The Adoption of Conservation Tillage Innovation on the Canadian Prairies

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ABSTRACT

One of the major innovations in Canadian agriculture over the last five decades has been the introduction of conservation tillage. Conservation tillage – a term that includes minimum or mulch tillage and zero-tillage (ZT) – was mainly introduced to combat land degradation and promote agricultural sustainability. By the end of the 1970s, conservation tillage, with all its components, had taken shape and was ready for adoption on the Prairies. Although some farmers had adopted ZT by the late 1970s and had found it profitable, this technology was not adopted on any major scale until the 1990s.

This thesis addresses the puzzle of why, if there was evidence of profitability, did the majority of farmers not adopt ZT during the 1980s. To solve this puzzle, this study examines the distributional consequences of ZT technology across both the different sectors involved in the provision of ZT and the different farmers that adopted this technology. In other words, this study determines the sectors that gain or lose from the adoption of ZT technology, and identifies the characteristics of farmers that affect the adoption of this technology.

To analyze the distributional impacts across the different sectors, an equilibrium displacement model is built to examine the welfare implications of the switch from traditional tillage to zero tillage on agricultural input suppliers in the spring wheat industry in 1989. The results reveal that the move to zero tillage decreases the rent accruing to the fuel sector, increases the rent received by the owners of land, machinery, herbicide and other variable inputs (e.g., seed, fertilizer), and has no effect on the rent to farm-owned labour. The aggregate change in the return to the industry is

positive, with most of the increase accruing to land owners. Two critical factors of ZT profitability were land ownership and the effectiveness of ZT equipment technology. Therefore, there is evidence that ZT was profitable for the group of farmers who own land and found the ZT equipment effective in 1989.

To examine the distributional impacts across the different farmers, a heterogeneous farmer decision-making model is built under a waiting option framework. The theoretical model shows the importance of neighbourhood and farmer characteristics in the adoption of zero tillage. Neighbourhood and farmer characteristics factors are empirically tested using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for the three Prairie provinces – Alberta, Saskatchewan and Manitoba – of Canada. The results of the empirical analysis show that CCSs closer to other CCSs with relatively high adoption of ZT tend, themselves, to have higher ZT adoption over time (neighbourhood effect). The results also show that education, farm ownership, large farm size, and soil erosion-high risk level positively influence the percentage of land under ZT technology. Distance to research station and brown soil type are found to be negatively impact the percentage of land under ZT.

Knowing the distributional impacts of technical change across the different sectors and across the different farmers is an important element to policy-makers and other groups involved in funding agricultural R&D investment decisions.

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Chapter 1

Introduction

The concept of sustainable agriculture, the ability of agriculture to provide continuous satisfaction of human needs for present and future generations, is gaining attention as the world population continues to grow.[1] The United Nations Department of Economic and Social Affairs (2002) indicated that natural resources are being consumed at an alarming rate, and that the capacity of resources and technologies to satisfy food demand for the growing population remains uncertain, especially as arable land is diminishing as a result of land degradation and the use of land for purposes other than agriculture.

Canada has about 38 Mha of arable land; of this, about 32 Mha is located in the Prairies (Campbell et al., 2002; Zentner et al., 2002).[2] Land degradation on the

[1] According to the U.S. Census Bureau, each year global population increases by about 80 million people and it is expected to reach about 9 billion by the year of 2040.

[2] The Canadian Prairies area covers the south of Alberta, Manitoba and Saskatchewan provinces, and is divided into five soil–climate zones, Black, Dark Grey, Grey, Dark Brown, and Brown. About 57% of the Prairies arable land is located in the Black, Dark Grey, and Grey soil zones, 22% in the Dark Brown soil zone, and the rest in the Brown soil zone (Campbell et al., 2002; Zentner et al., 2002). In general, Black and Grey soil zones are moister than Brown soil zones. For instance,

Canadian Prairies – this includes wind erosion, water erosion, and soil organic matter depletion, salinity, acidity, and nitrogen loss – has been recognized as problem by scientists for more than a century (Anderson, 1975; Hopkins et al., 1946; Gray, 1978; Janzen, 2001). The consequence of land degradation is a reduction in soil productivity through losses in nutrients, water storage capacity, and organic matter (Campbell et al., 1988, 1990). The major cause of land degradation is traditional tillage (TT), which requires the use of a fallow–crop rotation practice, combined with invasive cultivation for weed control on fallow and for seedbed preparation.

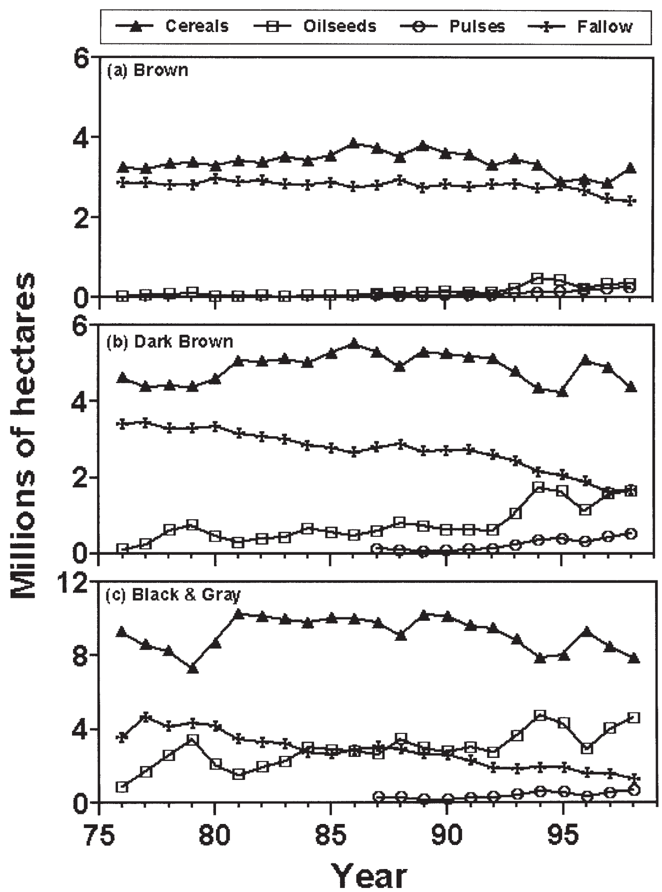
For a number of economic, technological and social reasons, TT emerged as and remained the dominant method of land cultivation on the Prairies from the time of European settlement until the last decades of the 20th century. Beginning in the 1970s and 1980s, however, a number of major changes began to occur in the crop mix and in the technology that farmers used to seed their crops. During the period 1976–1989, 17.5 Mha, 3.2 Mha, and 0.1 Mha of the arable land on the Prairies were sown on average to cereals, oilseeds, and pulses, respectively; an additional 9.8 Mha were under summerfallow (Figure 1.1).[3] These averages, however, mask a significant shift in land use. Although wheat acreage has remained relatively constant, the economic advantage of crop rotations, combined with an improvement in crop breeding, management practices and new technologies – particularly conservation tillage (CT), have resulted in an increase in the area sown to oilseeds (particularly

annual precipitation increases from 350 mm in the Brown soil zone located in the southern part to 475 mm in the Black and Grey soil zones located in the northern part of the Prairies (Zentner et al., 2002).

[3]During the period 1976–1989, about 2.8 Mha of the summerfallow area was located in the Brown soil zone; 3.4 Mha in the Dark Brown; and the remainder in the Black, Dark Grey, and Grey soil zones (Figure 1.1).

canola) and pulses and a decrease in the area under summerfallow in the 1990s (Figure 1.1).

Figure 1.1: Trends in Use of Arable Land in the Canadian Prairies



Source: Campbell et al. (2002)

The need to consider alternative tillage methods to TT was driven home by a number of high profile reports and studies that were published in the 1980s. The Prairie Farm Rehabilitation Administration (PFRA) (1983), Sparrow (1984), Fairbairn (1984) and the Science Council of Canada (1986) alerted the industry to the negative impact of traditional tillage on soil quality. The PFRA indicated that the practice summerfallow resulted in an annual soil loss of 227 metric tons by wind and water erosion on the Prairies. The PFRA (1983), Dumanski et al. (1986), and Van Kooten et al. (1989) estimated the annual cost of soil erosion on the Prairies at $239 million, between $155 and $271, and between $35.7 and 453.3 million, respectively. Rennie (1986) estimated the annual cost of land degradation (soil organic matter depletion, acidity, salinity, nitrogen loss, and erosion) resulting from the use of traditional tillage (TT) practices at $429.2, $560 and $43.7 million in Alberta, Saskatchewan, and Manitoba, respectively.

The alternative to TT – conservation tillage (CT) – was developed by pioneer farmers, engineers, scientists, and farm associations over a period of more than five decades (Carter 1994). Conservation tillage – a term that includes minimum or mulch tillage (MT) and zero-tillage (ZT) – is defined as a crop production system that keeps at least 30% of the previous crop residue on the soil surface, places seeds and fertilizers with little or no disturbance of the soil, controls weeds by herbicide or by minimal cultivation and herbicide, and uses crop rotations to break the life cycles of pests and diseases and help in controlling weeds (Carter 1994). Since ZT accounts for the highest adoption rate among the other forms of conservation tillage systems in the Canadian Prairies, it will be the focus of this thesis.

The adoption of ZT requires a dramatic change in the knowledge of the biophysical environment, the learning of new management practices and an investment in new inputs (e.g., new types of equipment). Eliminating tillage in preparing the seedbed and replacing tillage by herbicides to control weeds reduces the need for machinery operations and increases the need for herbicides. The reduction in machinery operations in turn reduces labour and fuel requirements.

By the late 1970s, ZT took shape on the Prairies after the introduction of the herbicide glyphosate by Monsanto, the development of commercial no-till drills by Versatile-Noble, Haybuster, and the development of new crop varieties such as canola by Dr. Downey at the AAFC, Saskatoon and Dr. Stefansson at the University of Manitoba and pulses by Dr. Slinkard at the Crop Development Centre (CDC), University of Saskatchewan.

Using the available zero tillage system, a few farmers such as Jim McCulcheon, Homewood, Manitoba; Bob McNabb, Minnedosa, Manitoba; John and Shirley Bennett, Biggar, Saskatchewan; Lucien and Herve Lepage, Montmartre, Saskatchewan; Gerry Willerth, Indian Head, Saskatchewan; Ike and Rod Lanier, Lethbridge, Alberta; and Murray Sankey, Veteran, Alberta adopted conservation tillage systems in the late 1970s. Lindwall and Larson (2010) interviewed the above farmers and reported the following. First, all adopters interviewed indicated that despite the limited equipment designs and the high price of glyphosate, growing a crop under CT was profitable. Second, all farmers experienced a significant improvement in their soil quality. Third, most early adopters reported facing social challenges that arose because they were not following the traditional tillage culture of the farming community.

Although some farmers had adopted zero tillage by the late 1970s, this technology was not adopted on any major scale before the 1990s; during the 1980s, the percentage of cropland under ZT on the Prairies was estimated to be between 3% and 10%

(AAFC 2010). Between 1991 and 2006, the percentage of cropland area under ZT practice in Alberta (AB), Saskatchewan (SK) and Manitoba (MB) increased from 3%, 10% and 5% to 48%, 60% and 21%, respectively (Statistics Canada, 1990-2006).

1.1 Problem Statement

The purpose of this thesis is to address the following puzzle in the adoption of ZT technology: Why, if there was evidence of profitablity, did the majority of farmers not adopt ZT technology during the 1980s? Were the early adopters of the zero tillage technology outliers and the rest of farmers saw no benefits from adopting this technology. Or were there other factors at work besides the economics? And why did farmers then begin to adopt this technology in the 1990s? Did the economics of ZT change? Or was there a social and information process at work that allowed the technology to spread from an initial group to the population at large?

To solve this puzzle and to answer these questions, we need to understand the distributional consequences of ZT technology across the different sectors involved in the provision of ZT and across the different farmers that adopted this technology. In other words, we need to determine the sectors that gain or lose from the adoption of ZT technology, and to identify the characteristics of farmers that impact the adoption of this technology.

Thus, the specific objective of this study is to break down the distributional effects of ZT technology across different sectors and across farmers to understand the adoption process of zero tillage technology in the Canadian Prairies. At the sectoral level, this study examines the changes in the costs and benefits of the switch from traditional tillage (TT) to zero tillage (ZT) technology and the distributional consequences of these changes across the different input suppliers in the spring wheat industry in 1989. The suppliers that are affected by the adoption of zero tillage are: land, labour, machinery, fuel, herbicide, and other variable inputs (e.g., seeds and fertilizer). The return to land is particularly important, because it is expected to help explain farmers' decision to adopt ZT technology. The spring wheat industry is chosen for the analysis because of its importance on the Prairies in 1989. The year of 1989 is chosen because data on zero tillage technology is not available before this year. We define the analysis of the sectoral impact as the vertical market analysis.

Across farmers, this study examines the distributional effects of ZT technology on heterogeneous farmers to identify the characteristics of the farmers that influenced the adoption of ZT on the Prairies. Of particular importance is the extent to which farmers that adopt ZT are located geographically close to other farmers that have previously adopted ZT. This neighbourhood effect is based on the assumption that since the adoption of ZT requires a significant change in the knowledge of the biophysical environment, learning of new management practices and investment in new inputs, this technology increases the effort and time required to learn about its performance and makes waiting valuable; waiting enables farmers to acquire more information on the performance of ZT from neighbours who have already used the technology, which in turn increases farmers stock of knowledge and, thus, positively influences the adoption of ZT.

In additional to its impact on learning process, neighbourhood effect could explain a number of different factors which might affect the adoption of ZT. For instance, it could explain the impact of the change in the social resistance to the zero tillage concept (i.e., as the number of farmers who have adopted ZT increases, social pressures or community expectations to follow traditional tillage culture decreases, and, thus, the adoption of ZT increases in the same neighbourhood over time), the impact of similar cultural or ethnic backgrounds, and the effect of similar agronomic conditions in the same neighbourhood on the adoption of ZT.

In addition to the neighbourhood variable, farmers' characteristics are divided into two groups: (1) farmer personal characteristics including farmer age, education, and off-farm employment; and (2) farm business characteristics including farm size, tenancy, distance to research stations and urban centre, and soil erosion and type conditions. The analysis is carried out over the period 1991–2006. We define the analysis across farmers as the horizontal market analysis.

1.2 Methodology

1.2.1 Vertical Market Analysis

This study uses an equilibrium displacement model to examine the change in the return to input suppliers as a result of the switch from TT to ZT technology in the spring wheat industry in 1989. The methodology applied in this study allows for the changes in the affected inputs (i.e., machinery, herbicide, labour and fuel) to influence not only the quantities used and prices of these inputs, but also of the other inputs in production (i.e., land and other variable inputs) via the change in the production function and the impacts of the output supply and demand elasticities, of inputs supply and demand elasticities, and of the elasticity of substitution between inputs. The changes in the quantities and prices of inputs affect in turn the welfare of all input suppliers in the industry.

The model assumes that the move to ZT technology represents a shock to the equilibrium system. This shock changes the efficiency and/or the price of the affected production factors. The change in the efficiency of inputs is treated by modifying the production function using the specification of the factor–augmenting technical change approach. The change in the price of inputs is treated by shifting the corresponding input supply functions.

1.2.2 Horizontal Market Analysis

This study builds a heterogeneous farmer decision-making model under a waiting option framework. The theoretical model shows the importance of neighbourhood and farmer characteristics in the adoption of ZT. Neighbourhood and farmer characteristics factors are empirically tested using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for the three Prairie provinces – Alberta, Saskatchewan and Manitoba – of Canada.

1.2.3 Organization of Thesis

The rest of this study is organized as follows. Chapter two surveys the historical factors behind the development and adoption of conservation tillage technology in the Canadian Prairies during the 1930s and 1990s. Chapter three describes the equilibrium displacement model. Chapter four estimates the welfare implications to different agricultural input suppliers as a result of the switch from traditional to zero-tillage technology in a vertical market relationship. In chapter five the results of the empirical work, which examines the effects of neighbourhood and farmer characteristics on the adoption of ZT in a horizontal market relationship, are presented, after a description of the database, and an overview of the theoretical model and empirical methodology. Finally, chapter six summarizes the main findings and concludes the study.

Chapter 2

The Development and Adoption of Conservation Tillage Innovation on the Canadian Prairies

2.1 Introduction

An innovation is defined as a new idea, method, custom, or object that is perceived as new by those who adopt it and used to perform a new task (Rogers, 1995). Agricultural innovations can take the form of agronomic innovations (i.e., new management practices), mechanical innovations (i.e., new machinery), biological innovations (i.e., new seed varieties), chemical innovations (i.e., new herbicides and fertilizers), and biotechnological innovations (i.e., new genetically modified seeds). In addition, agricultural innovations can be classified based on their economic impacts – innovations that increase yields, reduce cost, enhance product quality, or protect environmental health (Sunding and Zilberman, 2001).

Conservation tillage is an innovation package that consists of a number of components including new management practices, herbicide, equipment, and crop varieties.

Conservation tillage – a term that includes minimum or mulch tillage and zero tillage – is a sustainable agricultural practice that requires a considerable increase in the knowledge of the biophysical environment, learning of new management practices and investments in new inputs. Compared with traditional tillage, conservation tillage requires that farmers keep at least 30% of the previous crop residue on the soil surface, place seeds and fertilizers with little or no disturbing of the soil through tillage, control weeds by herbicide or by minimal cultivation and herbicide, and use of crop rotations to break the life cycles of pests and diseases and help in controlling weeds (Carter, 1994; Coughenour and Chamala, 2000; Ekboir, 2003; Gray, 1978).

The innovation process can either be conceived as being linear or system – oriented. The linear model of innovation envisions a uni-directional flow from basic research, to applied science, to the development of a new product that is marketed and adopted by users (Kline and Rosenberg, 1986). The innovation system approach views innovation as emerging from the complex interactions between different participants (public research institutes, universities, business firms, government, etc.) in the generation and application of knowledge (Freeman, 1987; Lundvall, 1992).[1] Each actor in the system participates in innovation networks that include several feedback loops that can occur at any stage of knowledge generation and may stimulate learning (OECD, 1999). Knowledge sharing among actors through networks leads to value-creation processes that motivate actors to share and exchange knowledge with the objective of learning. Thus, the most important resource in innovation systems

[1]The concept of innovation system: is derived from more general theoretical work on national innovation systems (NIS), carried out by Freeman (1987, 2002), Lundvall (1985, 1992, 2002, 2007), Metcalfe (1995), Nelson and Rosenberg (1993), Porter (1990), Romer (1990), Nelson (1987) and others.

is knowledge and the most important process is learning (Lundvall, 2007).

On the Prairies, conservation tillage innovation occurred in an innovation system that involved pioneer farmers, engineers, scientists, and farmer associations who worked together and interacted for a period of more than five decades. During this time, the innovation activities of different actors in the system were guided by a set of environmental, economic, policy, and social factors. By the end of the 1970s, conservation tillage with all its components – management practices, herbicide, equipment, and crop varieties – took shape and was ready for adoption.

In the Canadian Prairies, conservation tillage was mainly introduced to combat soil degradation and promote agricultural sustainability. Soil degradation prevents crop growth through losses in nutrients, water storage capacity, and organic matter, and can contribute to other aspects of the environment such as increases in greenhouse gas emissions (AAFC, 2010).

The main land degradation issues on the Prairies are soil erosion, organic matter depletion, and salinity. Soil erosion is the movement of soil from one area to another by wind or water. Soil organic matter is an indicator of soil fertility and water–holding capacity. Intensive use of traditional tillage reduces soil's natural fertility by transforming soil organic matter. Cultivating the soil and removing plant residues from the surface of the ground accelerates the decomposition of the organic matter particles (silt and clay particles) into small granules, and promotes a soil condition susceptible to erosion by releasing these particles for transport by wind and water (Hopkins et al., 1946). Soil salinity occurs when the soil contains high level of dissolved salt that hinders plant growth by reducing its ability to absorb water and nutrients. Traditional tillage, particularly summerfallow, increases soil salinity by moving the salt with the rising groundwater, and accumulates it on the soil surface and the root zone (AAFC, 2010).

Between 1991 and 2006, the percentage of cropland area under zero tillage practice in Alberta (AB), Saskatchewan (SK), and Manitoba (MB) increased from 3%, 10%, and 5% to 48%, 60%, and 21%, respectively (Figure 2.2). The increased use of conservation tillage, particularly zero tillage, contributed to the reduction of all forms of land degradation on the Canadian Prairies (Figures 2.2, 2.3, 2.4 and 2.5).

Figure 2.3 represents the percentage of cropland area that falls into five soil erosion risk classes measured by the rate of soil loss (AAFC, 2010).[2] Between 1991 and 2006, the percentage of cropland area in the Very Low soil erosion risk class in AB, SK and MB increased from, 63%, 48% and 63% to 87%, 87% and 79%, respectively. During this period, the prairies' cropland area in the Moderate , High and Very High soil erosion risk classes decreased, on average, by around 12% (Figure 2.3). Figure 2.4 represents the percentage of cropland area that falls into five soil organic carbon (SOC) change classes.[3] In 2006, 28%, 69% and 31% of the cropland areas in AB, SK and MB were in the Large Increase SOC class, respectively. This is

[2]The AAFA (2010) uses the SoilERI to estimate the risk of soil erosion at the Soil Landscape of Canada (SLC) polygon scale. The risk of soil erosion is measured by the rate of soil loss and reported into five classes: Very Low is when an area loses less than 6 tons per hectare per year, Low loses 6 to 11 t $ha^{-1}yr^{-1}$, Moderate loses 11 to 22 t $ha^{-1}yr^{-1}$, High loses 22 to 33 t $ha^{-1}yr^{-1}$ and Very High loses more than 33 t $ha^{-1}yr^{-1}$.

[3]The AAFA (2010) uses the Century model (NREL, 2007) to estimate the rate of change in the soil organic carbon (SOC) in Canadian agricultural soils as a result of the change in management practices since 1951. The percentage of cropland falls into five SOC change classes expressed in kg per hectare per year. The five classes are Large Increase gains more than 90 kg $ha^{-1}yr^{-1}$, Moderate Increase gains 25 to 90 kg $ha^{-1}yr^{-1}$, Negligible changes by 25 to -25 kg $ha^{-1}yr^{-1}$, Moderate Decrease loses -25 to -90 kg $ha^{-1}yr^{-1}$, Large Decrease loses more than -90 kg $ha^{-1}yr^{-1}$.

a significant improvement over 1981 when only 1%, 0%, and 12% of these areas were in this class (Figure 2.4). Figure 2.5 represents the percentage of cropland area that falls into five soil salinization risk classes.[4] Between 1991 and 2006, the percentage of cropland area in the Very Low soil salinity risk class in AB, SK, and MB increased by around 5%, 4%, and 20%, respectively. During this period, the prairies' cropland areas in the Moderate , High and Very High risk of salinization classes decreased on average by around 5% (Figure 2.5).

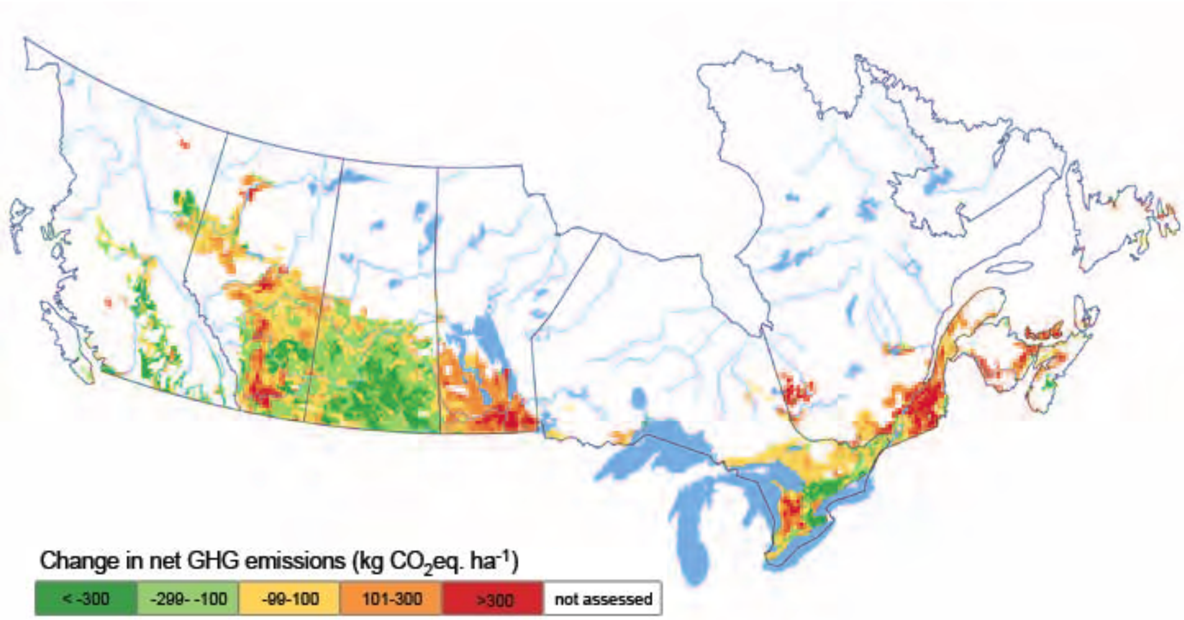
In addition to its impacts on soil quality, conservation tillage has other environmental benefits such as carbon sequestration and reducing carbon dioxide emitted during fossil–fuel combustion by farm equipment. Conservation tillage systems have carbon sequestration potential through storing the organic matter in the soil. When the soil is tilled, soil top layers are turned over, air mixes in, and soil microbial activity increases over baseline levels. As a result, soil organic matter is broken down rapidly, and carbon is lost from the soil into the atmosphere. Moreover, since traditional tillage requires more machinery passes than conservation tillage, emissions of carbon dioxide from energy use and fossil fuel consumption are higher than under conservation tillage (AAFC, 2010; Lal, 2004; USDA, 2004).

In Canada, net agricultural greenhouse gas (GHG) emissions (excluding fossil–fuel emissions) decreased from 45.3 Mt CO_2e in 1981 to 44.8 Mt CO_2e in 2006 (AAFC, 2010). GHGs emitted from agriculture are nitrous oxide (N_2O) and methane (CH_4), while carbon dioxide (CO_2) can be either emitted or absorbed (AAFC, 2010). This decline in GHG has occurred despite an increase in methane (CH_4) emission from

[4]The AAFC (2010) uses a unit-less Salinity Risk Index (SRI) that contains weightings for factors influencing the salinization process.

21.7 MT CO_2e in 1981 to 27.9 MT CO_2e in 2006; and an increase in nitrous oxide (N_2O) emission from 22.6 MT CO_2e in 1981 to 28.7 MT CO_2e in 2006. The increase in CH_4 and N_2O emissions are mainly due to an increased animal population during this period. The reason behind the 1.1 % reduction in net agricultural GHG emissions in Canada is that soil has changed from a 1 Mt CO_2e source of emissions in 1981 to a 11.7 Mt CO_2e sink of emissions in 2006, which has offset the increase in CH_4 and N_2O emissions. The change in soil CO_2 is mainly due to the widespread adoption of conservation tillage technology on the Prairie Provinces (AAFC, 2010). Figure 2.1 shows that Saskatchewan accounted for the highest reduction in net agriculture GHG emissions in Canada during 1981 and 2006 (in Figure 2.1, a negative value indicates a reduction in net agricultural GHG emissions).

Figure 2.1: Net Change in Agriculture Greenhouse Gas Emissions in Canada (1981–2006)

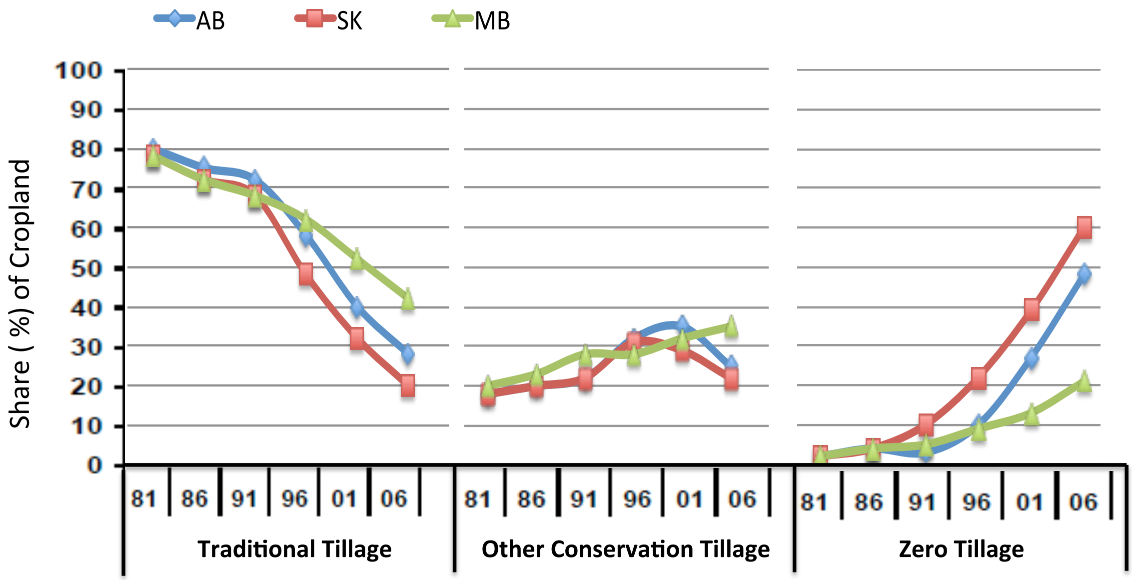


Source: AAFC (2010)

Farmers' decision to switch from traditional to conservation tillage did not occur on any major scale before the 1990s (Figure 2.2). This was due to the following barriers: a) technical inefficiency of weed control methods and seeding equipment in the early days of conservation tillage development; b) low profitability and high complexity of conservation tillage: compared to traditional tillage, conservation tillage systems require learning new management practices and use of new and more expensive inputs; c) policy barriers such as the Canadian Wheat Board's delivery quota system and Lower Inventories For Tomorrow (LIFT) program; (d) incompatibility of conservation tillage with farmers' sociocultural values and beliefs. For instance, tilling the soil was a part of an adaptive culture that was shared and recognized by others in the farming community and considered the fundamental task in producing a crop and providing a living for farmers. Thus, adopting a reduced or no-till crop production system was perceived by farmers as incompatible with their values and beliefs.

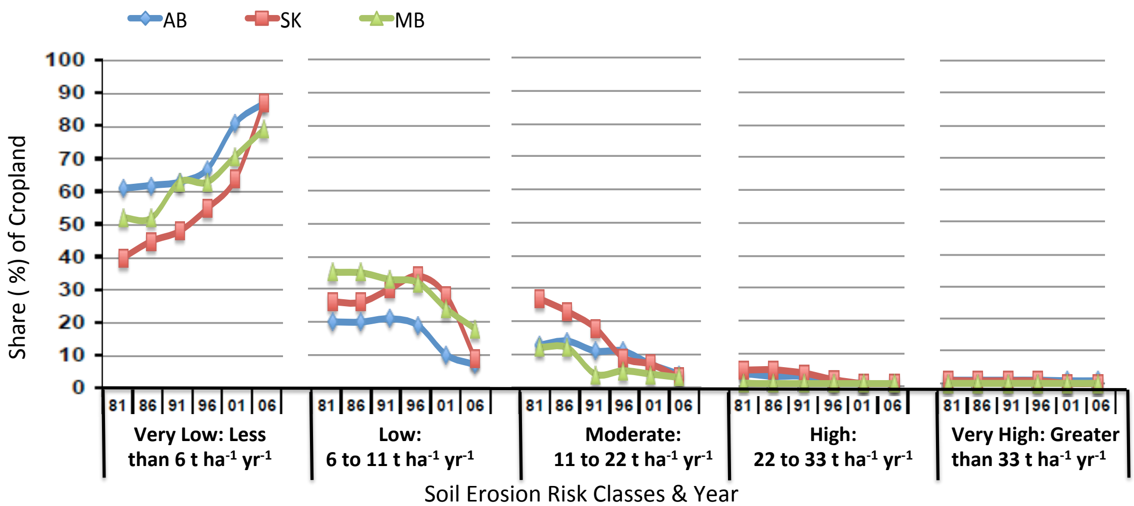
This chapter surveys the factors behind the development and adoption of conservation tillage systems on the Canadian Prairies in the period between the 1930s and 1990s. Particularly, this chapter describes how environmental factors such as land degradation and climate conditions induced the development of conservation tillage technology, while economic, policy, and social factors delayed its development and adoption between the 1930s and 1960s. Then, a review of the driving factors which resulted in the development and widespread adoption of conservation tillage technology during the 1970s and 1990s is presented.

Figure 2.2: Tillage Systems Trends on the Canadian Prairies (1981–2006)



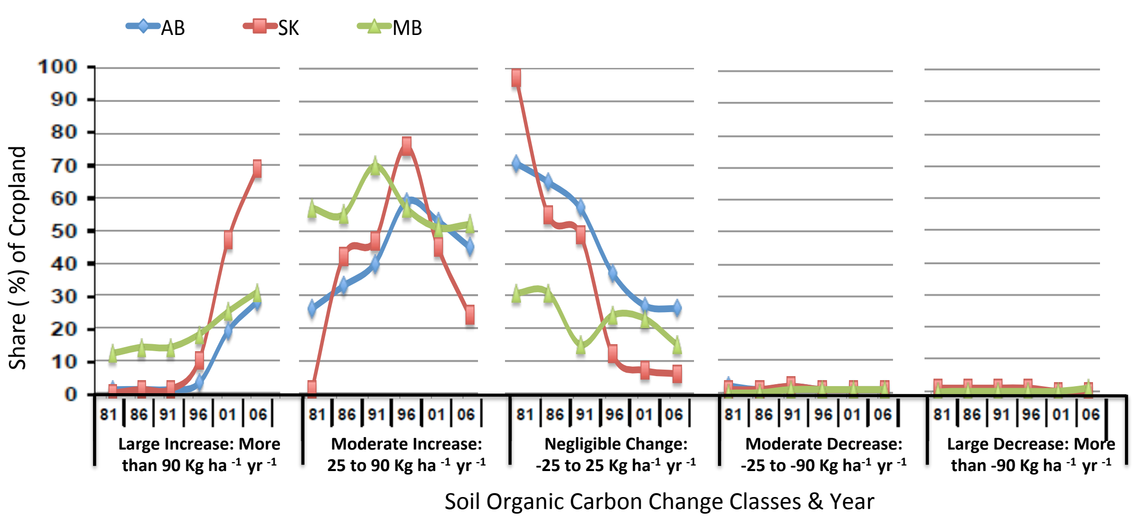
Source: Li, Lobb and McConkey (2010)

Figure 2.3: Soil Erosion Risk on the Canadian Prairies (1981–2006)



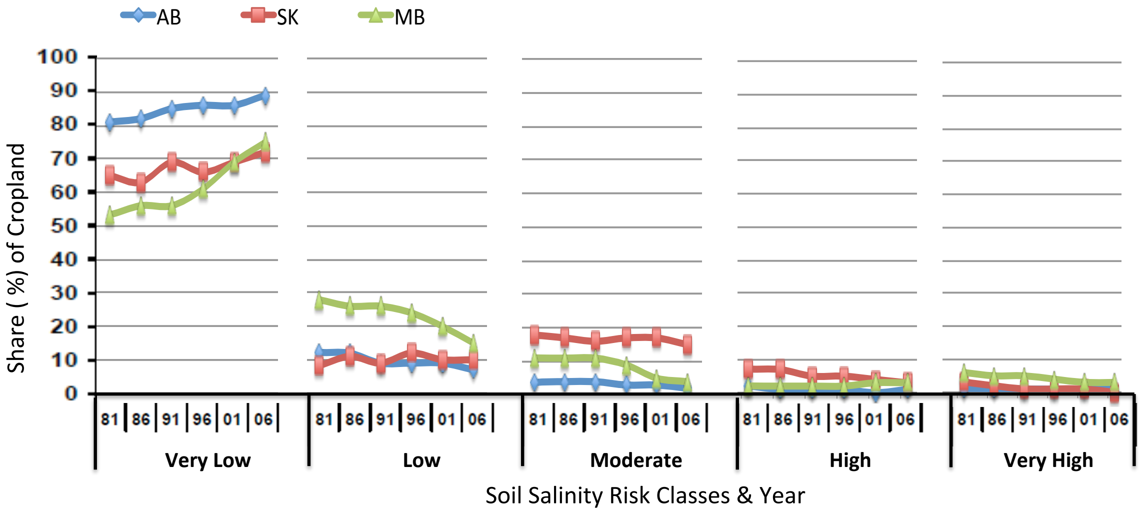
Source: Figure Based on Data Analysis by Agriculture and Agri-Food Canada (2010)

Figure 2.4: Soil Organic Carbon Change on the Canadian Prairies (1981–2006)



Source: Figure Based on Data Analysis by Agriculture and Agri-Food Canada (2010)

Figure 2.5: Soil Salinization Risk on the Canadian Prairies (1981–2006)



Source: Figure Based on Data Analysis by Agriculture and Agri-Food Canada (2010)

2.2 The Development and Adoption Path of Conservation Tillage Innovation on the Canadian Prairies

The development and adoption path of the conservation tillage innovation on the Prairies can be divided into three time periods, the 1930s to 1940s, the 1950s to early 1970s, and the early 1970s to 1990s.

2.2.1 The 1930s and 1940s – Land Degradation and the Early Development of Conservation Tillage Practices

In the early days of the Prairies settlement, farmers, coming from areas characterized by high precipitation, had learned to farm with moldboard plows, disks, and harrows. Using the available techniques and their limited knowledge of the Prairie soil and climate conditions, farmers engaged in tillage activities, which from their point of view were necessary to prepare the land for cropping (Anderson, 1975). The use of tillage rested on the belief that removing the residue from the field surface was needed to aerate the soil, improve soil structure, control plant diseases, insects, and weeds, and facilitate cultivation for a finely tilled seedbed. After years of practicing, tillage became the activity that symbolized the farmer's role in his rural community (Coughenour and Chamala, 2000).

Facing the semi-arid climate of the Prairies, farmers adopted summerfallow as an additional practice in their tillage system. Summerfallow, which was discovered accidentally by Dr. Angus Mackay of Indian Head in 1886, is the practice in which land is not cropped for a period of 20 months starting from late September to mid April of the following next year (Kirk, 1938).[5] Summerfallow is mainly used to in-

[5] Dr. Angus Mackay (1841–1931), a farmer, was born near Pickering township, Upper Canada.

crease soil water reserve (although it reserves only 30% or less of the precipitation received) to ensure there is adequate moisture to grow a crop the next growing season (Carter, 1994). Weeds, during the smmerfallow period, are controlled either with tillage or herbicides (called chem-fallow). Farmers following chem-fallow had to apply five times more herbicides such as paraquat (introduced in 1961) and glyphosate (introduced in 1974) than under traditional summerfallow (Kulshreshtha and Storey, 1999).

The Dirty Thirties and the Search for More Sustainable Agriculture Practices

In the 1930s, the area experienced a period of severe drought and a number of dust storms. The result was that the period was named the Dirty Thirties, while the area became known as the Dust Bowl. Because of the large area under summerfallow, high winds moved millions of metric tons of topsoil from fields in the affected areas in the 1930s. The action of wind on land under summerfallow was not the only contributing factor to soil erosion at that time. Anderson (1975) indicated that the main reason was that a whole plowing culture was introduced on the Prairies without any adjustment to the ecological environment of this area, and that the introduction of this culture coincided with periods of low precipitation, and the breaking of large amounts of land as a response to the advent of mechanization and the high prices of

He moved to Indian Head at the age of 40 to start working on his own land. In 1885, the Riel Rebellion battle required farmers to transport equipment and supplies to forces in Battleford and Prince Albert. It happened that Mackay's horses weren't fit to travel and, in the same year, the frost prevented him from seeding his farm, so he just used his horses to plow and harrow the field periodically to control weeds in the summer. Accidentally he was preparing for the first summerfallow in Western Canada. The following year was very dry and Mackay's summerfallow resulted in exceptional yield, 35 of bushes per acre, while his neighbours' crops were ruined (Kirk, 1938).

grains brought on by the First World War.

In the search for answers on how to control soil drifting in the 1930s, governments, experimental farms, universities, and farmers launched co-operative efforts. Soil scientists, such as W. S. Chepil and Sidney Barnes, confirmed that tillage should be kept to a bare minimum, land should only be worked to control weeds, and trash should be kept on the surface to prevent soil drifting (Gray, 1978). In 1935, the federal government established the Prairie Farm Rehabilitation Administration (PFRA), including the establishment of the experimental substations, agricultural improvement associations (AIAs), community pastures, water projects, and shelterbelt programs.

The role of PFRA was to work together with experimental farms, universities, provincial agencies, and farmers to share knowledge and feedback with the objective of developing more sustainable agriculture practices to control soil drifting. The AIAs, which were coordinated by the Dominion Experimental farms, facilitated the two-way flow of information among different actors in the network (Gray, 1978).

The result of these co-operative efforts was more sustainable practices such as trash–cover, ploughless fallow, and strip farming practices using one-way discers, duckfoot cultivators, the Morris rod weeder, and wide-blade cultivator. Although these soil conservation practices could, to some degree, control soil erosion at that time, the available equipment was not fully effective in controlling weeds, and the crop residues left on the surface by the blade cultivator made seeding more difficult because of trash clearance and plugging problems (Gray, 1978).

The early development of soil conservation practices happened during the Great Depression in the 1930s. This era of privation and uncertainty drove farmers to think solely about immediate survival. Thus, investment in new sustainable agriculture practices to replace tillage culture wasn't an option for farmers at the time. In addition, machinery companies had an economic stake in powerful tractors and tillage equipment, and in planters that best worked in tilled soil, thus, they had no incentive to invest in the development of alternative equipment that could replace tillage and planting equipment.

2.2.2 The 1950s to Early 1970s – The Initial Trial of Low-Disturbance Direct Seeding

The efforts to develop proper equipment for trash farming and reducing tillage continued on the Prairies. By the 1950s, the discer with an attached seed box was introduced. The discer was a Saskatchewan innovation, that left more trash on the surface, was larger in size than its antecedent, and able to accomplish tillage and seeding in one pass. Saskatchewan manufacturers also contributed to the development of heavy–duty cultivators (also known as chisel plows) that could clear more trash and leave more surface trash than disc-type machines. Another important contribution to trash-cover equipment was the development of a coil land packer by Emerson Summach (a Saskatchewan farmer who would become the owner of Flexi–Coil). The coil packer could follow the contours of the land, worked in stony land, and reduced the disturbance of the soil (McInnis, 2004). Although all of these equipment innovations were important contributions toward reducing tillage, tilling the soil was still fundamental controlling weeds and producing a crop at that time.

The trend after World War II was to move toward larger farms and wider equipment. This movement made trash and strip farming practices inconvenient and resulted in an increase in tillage equipment investment that allowed farmers to substitute machinery for labour and increase their farm size.

Low-disturbance Direct Seeding Initial Trial

In 1961, the first herbicide for broad–spectrum weed control, paraquat, was produced for commercial purposes by Imperial Chemical Industries (UK). With paraquat, replacing tillage with herbicide to control weeds for summerfallow (chem–fallow) became possible. In addition, in 1967, the first no–till drill equipment by Allis–Chalmers was introduced on the Prairies. With the introduction of the herbicide paraquat and no–till drill seeder, researchers, such as C.H. Anderson at Swift Current, Tracy Anderson and Wayne Lindwall at Lethbridge, Ken Browren at Melfort, Elmer Stobbe at the University of Manitoba, and Brian Fowler at the University of Saskatchewan were able to experiment with the production of a crop under a low–disturbance direct seeding system and reported that yields under this system were as good as those under a traditional tillage system (McConkey, 2010).

These two factors provided farmers with the necessary components to produce a crop under a low–disturbance direct seeding system. However, the high price of paraquat and its inadequate control of broadleaf weeds, together, with the cost and limited success of no–till drills available from the United States that had problems with seed placement and ineffective packing were regarded as deterrents to the adoption of this system on the Prairies in the 1960s (McConkey, 2010).

Policy Barriers to the Adoption of Conservation Tillage

During the period between 1953 and 1973, the Canadian Wheat Board's delivery quota system, and the way this quota was designed to include summerfallow in the category of assignable acres, was seen as a deterrent to the adoption of conservation tillage on the Prairies (Gray, 2010; Hildebrand, 1983; Sparrow 1984). The primary objective of the delivery quota, as set forth in 1940, was to provide producers on the Canadian Prairies and the Peace River District of British Columbia with equitable access to the transportation and marketing system (Sampson and Gerrard 1987 and Hildebrand 1983).[6] During the period from 1940 to 1953, delivery quotas enabled producers' to deliver a quantity of grain proportional to seeded acreages.[7] In 1953, the grain market demand dropped dramatically and the CWB was unable to accept all producers grain deliveries. An excess stock of a particular crop under seeded acreage quota would only be marketed if a producer replanted it or if a future crop failed. This showed the weakness of the seeded acreage quota and led to the establishment of the general delivery quota system based on a producer's specific acreage. The general delivery quota remained in effect until 1973, and allowed a producer to market aggregate crops proportional to specified acreage. Specified acreage included the area seeded to crops controlled by the quota (i.e., wheat, oats, barley, and rye), land

[6]In 1939, world price declined below the floor price of $0.9 per bushel, World War II prevented the Canadian grain from being marketed in Europe, Canadian production was above normal, and elevator space was very tight. Because of these factors, the Canadian Wheat Board (CWB) imposed a 5000–bushel quota of wheat per farmer in 1939. This quota was replaced by the first delivery quota system on August 7, 1940 (CWB, 1998).

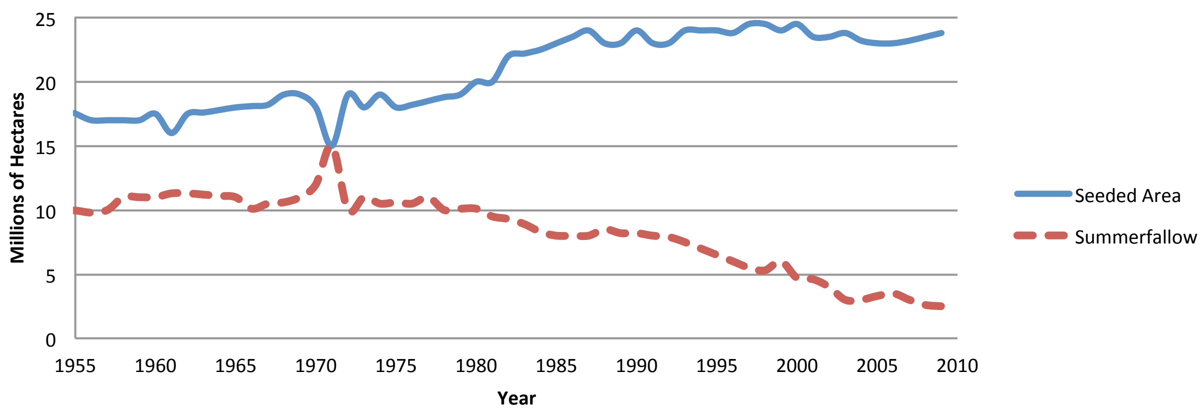
[7]During 1944 and 1952, quotas levels were open as a result of the strong grain markets after World War II. That is, farmers who produced more than their quota could market the excess before the end of the crop year (Jolly and Abel, 1978).

under summerfallow, and eligible grasses and forage crops (Jolly and Abel, 1978).[8] Including summerfallow in the category of the assignable acreage was in fact an act that encouraged producers to summerfallow. For instance, since a farmer's delivery base was constant regardless of his set of land use decisions, farmers found it more economical to increase the number of acres under summerfallow relative to seeded acres to save the cost of variable inputs per unit of output. In addition, in the case of excess stocks of a particular year, a farmer could obtain a marketing quota for grain inventory in the following year by just working the land and leaving it idle.

In 1969, after more than 16 years of abundant production and limited export permits, the Canadian wheat stock built up and reached about two years of average production (Jolly and Abel, 1978). This led to the introduction of the federal Lower Inventories For Tomorrow (LIFT) program in 1970. LIFT was a one-year program designed to immediately reduce wheat inventory by reducing seeded wheat acreage and converting it to summerfallow or sowing it to perennial forage. Under LIFT, producers were paid \$6 per acre for converting wheat acreage into summerfallow, and \$10 per acre for seeding this land to perennial forage (Cohn, 1977). As a result, in 1971, the seeded wheat acreage fell by 50% and wheat inventory went down by 40% (CWB, 1998). Although this program had met its goal, it dramatically increased the area under summerfallow on the Prairies. Figure 2.6 shows that the area under summerfallow increased from around 10 to 15 million hectares as a result of the introduction of LIFT in 1970.

[8] In 1972, the general delivery quota system was expanded to include land seeded to rapeseed and flaxseed, and land in miscellaneous crops such as sunflowers.

Figure 2.6: Seeded and Summerfallow Areas on the Canadian Prairies (1955–2009)



Source: Van Kooten et al. (2011)

2.2.3 The Early 1970s to the 1990s – The Driving Forces behind the Development and Adoption of Conservation Tillage System on the Prairies

In 1973, the market for grain received a dramatic shock after the entry of the Soviet Union in the market for grain for the first time. The result of this was a decrease in North American grain reserves and a substantial increase in grain prices. In 1974, the New Domestic Feed Grains Policy (NDFGP) was introduced in Canada. This policy eliminated the CWB's control over interprovincial movement of feed grains and created a dual marketing system. This system gave farmers the option of selling their feed grains to the CWB, to companies (private and co-operative), or both (CWB, 1998). As a response to these factors, farmers increased their production by increasing the seeded area using traditional tillage systems (Figure 2.6). Intensive tillage combined with severe drought resulted in more damage to soil quality in the early 1970s (Lindwall, 2009).

The Introduction of Herbicide Glyphosate

In 1974, Monsanto Company introduced the broad–spectrum herbicide glyphosate under the trade name Roundup (Monsanto website).[9] Both glyphosate and paraquat are regarded as low–risk non–selective herbicides that can be used to control a wide range of weeds before seeding and in fall. The price of paraquat was lower than the price of glyphosate in the 1970s, but glyphosate provided better weed control. The mode of action of paraquat provided limited control of grass species such as wild oats and volunteer cereals and only controled the top–growth of perennial weeds. The ability of glyphosate to move throughout the plant and reach deep into the roots provided more efficient weed control, especially controlling rooted perennials with tubers and rootstocks (Blackshaw and Harker, 2009).

The Development of New Crop Varieties

Conservation tillage systems require the use of crop rotations that break the life cycles of pests and diseases, and help in controlling weeds. Crop rotations also contribute to higher and more diversified sources of farm income by providing farmers with the opportunity of not using summerfallow and keeping fields under continuous production. Between the 1970s and 1980s, advances in crop breeding resulted in the introduction of new varieties of oilseeds and pulses that could be used in rotation

[9] In 1974, Roundup was developed and commercialized in Malaysia and the UK, and used in the US for industrial purposes. In 1976, Roundup was commercialized for agricultural use in the US (Monsanto Company, 2011).

with cereal crops on the Prairies. The increased area sown to oilseeds and pulses replaced, to a large degree, the area under summerfallow and thus influenced the adoption of conservation tillage on the Prairies (Campbell et al., 2002).

In 1973, the first rapeseed to contain less than 2% erucic acid and not more than 3 mg/g of glucosinolate dry meal was introduced on the Prairies. The new rapeseed variety was registered by the Western Canadian Oilseed Association under the trade name "Canola" in 1979 (McInnis 2004).[10] The precursor to canola was initially naturally bred from rapeseed by Dr. Keith Downey at the AAFC Research Centre in Saskatoon and Dr. Baldur Stefansson at the University of Manitoba. In the mid 1960s, a co-operative effort between the two scientists was formed to eliminate the two components - erucic acid and glucosinolate - in rapeseed.[11] In 1967, Downey and Stefansson developed the first low-erucic-acid (LEAR) rapeseed variety. In the same year, Jan Krzymanski, a scientist from Poland, visited the Saskatoon Research Centre (SRC) and presented the *B. napus* variety – a rapeseed variety that contains a very low level of glucosinolate. Downey and Stefansson used the *B. napus* discovery and each came up with a variety that was low in both erucic acid and glucosinolate in 1973. Dr. Stefansson's variety, Tower, was registered by Agriculture Canada as the world's first zero-erucic-acid, low glucosinolate *B. napus*. In 1977, Dr. Downey and breeder Sid Pawlowski from SRC developed the world's first zero–erucic, low glucosinolate *B. campestris* variety "Candle" (McInnis, 2004).

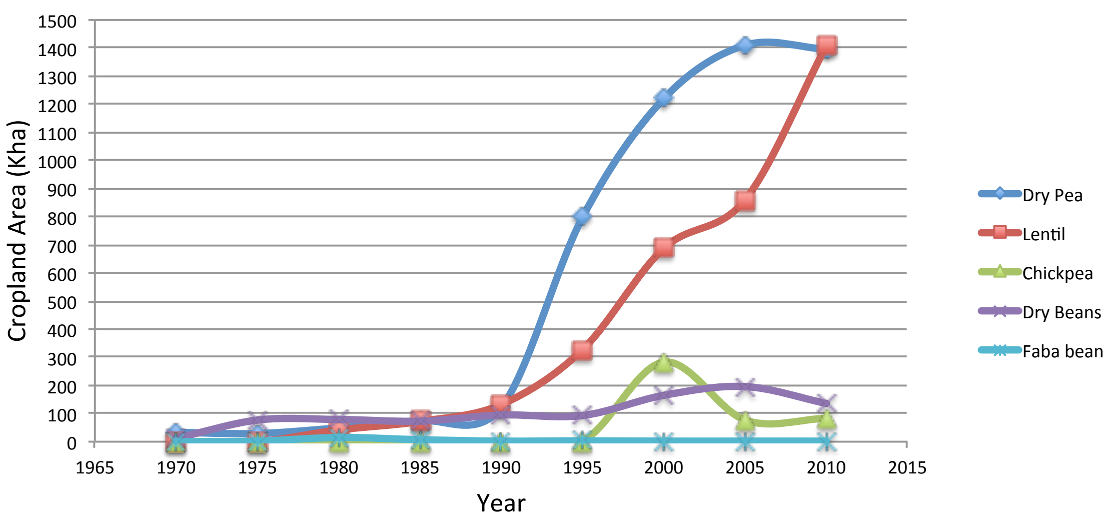
During the 1970s and 1980s, pulse crops (peas, dry beans, lentils, chickpeas,

[10]The name Canola was derived from Canadian Oil, Low Acid.

[11]During the 1960s, nutritionists reported that the high erucic acid oil in rapeseed could increase cholesterol and cause heart damage. The high level of glucosinolate is the main barrier to the use of rapeseed meal in livestock feed (Pixton and Warburton, 1977).

faba beans) were virtually not grown on the Prairies (Figure 2.7). The development of new pulse varieties set the stage for future growth of these crops on the Prairies (Saskatchewan Pulse Grower (SPG), 2000). Today, Canadian farmers, primarily Prairie farmers, plant a pulse area of more than 3 Mha (1.396 kha, 1.408 kha, 136 kha, 83 kha are sown to peas, lentils, dry beans, and chickpeas, respectively) and produce around 5.2 Mt of pulses (peas, 2.862 kt; lentils, 1.947 kt; dry beans, 254 kt; and chickpeas, 128 kt) (AAFC, 2011). The expansion of pea, lentil, and chickpea crops makes Canada the world's leading exporter of these crops (Blade and Slinkard, 2002).

Figure 2.7: Area Seeded to Pulse in Canada (1970–2010)



Source: Figure based on Data by Agriculture and Agri-Food Canada (2002, 2005, and 2011) and Blade and Slinkard (2002)

The development of new lentil varieties by Dr. Alfred Slinkard, at the Crop Development Centre (CDC), University of Saskatchewan, contributed to the expansion of this crop on the Prairies.[12] In 1972, Dr. Slinkard tested the USDA Plant Introduction Station lentil collection at the CDC. As a result, in 1978 and 1980, he developed the "Laird" lentil (large-seeded) and "Eston" lentil (small-seeded) varieties. Laird soon became the most grown lentil variety on the Prairies. In 2000, Prairie farmers seeded around 500 kha of Laird, the world's largest seeded area of this crop (Blade and Slinkard, 2002).

During the 1970s, a number of pea varieties, introduced by European countries, were available on the prairies (SPG, 2000). However, during this period, the development of the pea industry was very slow because of the difficulties of finding markets. In 1985, the European Economic Community (EEC) became less reliant on imported livestock protein supplements (i.e., soybean meal and corn gluten meal) and switched to domestic peas as the major protein source. But, the EEC demand for protein peas exceeded its domestic supply, forcing it to import huge quantities of dry peas from other countries. With the opening of the EEC feed pea market and the resulting high price, Prairie farmers responded and expanded the area sown to peas. Figure 2.7 shows that, in 2010, Canadian farmers planted pea area of 1.4 MHa. In the same year, Canada produced around 2.8 Mt of peas and exported about 60% of this production to Europe, South America, and Asia (SPG, 2000; AAFC, 2011).

Two types of chickpeas are grown on the Prairies, the large–seeded "Kabuli" (garbanzo bean) with a thin, delicate, colourless seed coat and the smaller–seeded

[12] In 1971, the Crop Development Centre was established at the University of Saskatchewan, in collaboration with the Province of Saskatchewan and the National Research Council of Canada (Blade and Slinkard, 2002).

"Desi" with a thick, tough coloured seed coat. During the 1980s, most chickpea crops grown on the Prairies were undersized and usually devastated by ascochyta blight infection (an infection that can not only destroy the current chickpea crop, but also the next two–year crops, if a trace seed–borne ascochyta infection is still present). In 1993, Fred Muehlbauer, USDA Pulse Breeder at Pullman, Washington, introduced "Sanford" and "Dwelley", two Kabuli chickpea varieties, and in 1994, he released the Myles, a Desi chickpea variety, that are partially resistance to ascochyta blight (Blade and Slinkard, 2002). Using the new varieties, farmers increased the area sown to chickpeas from 2 Kha in 1995 to 283 Kha in 2000 (Figure 2.7). Today, additional Kabuli varieties such as Yuma and Xena, and Desi varieties such as Myles and Desiray, introduced by the CDC, are available to farmers. The CDC is still working on improving the size of Kabuli varieties to capture the extra-large-seeded price premium (Blade and Slinkard, 2002).

Previous studies indicated that including pulse crops in rotation with cereals provide farmers with additional benefits by reducing the costs of fertilizer in the year of growing the pulse crop and in the subsequent year of growing the grain crop (Grant et al., 2002; Zentner et al., 2002). Pulse plants contain nitrogen-fixing symbiotic bacteria in root nodules that are able to fix atmospheric N in a form that plants can use. Nitrogen is the most important nutrient for crop growth and a major concern with regard to environmental sustainability (NO_3 leaching can reduce ground water quality and N_2O emissions can contribute to the greenhouse gas effect and global warming) (Zentner et al., 2002). In addition, since nitrogen is an integral component of protein, nitrogen released from decomposing pulse residues can increase the protein content of subsequent grain crop and thus decrease fertilizer phosphorous (P) requirement (Grant et al., 2002).

The Early Adoption of Conservation Tillage System

During the 1970s, Ben Dyck at AAFC, Swift Current, stimulated the development of commercial no-till drills by Versatile–Noble, Haybuster, and other manufacturers (McConkey, 2010). With the introduction of glyphosate, new alternative crops, and the improvement of direct seeding equipment (i.e., disc drill and hoe drill) conservation tillage systems began to take shape by the end of the 1970s.

Using the available conservation tillage system, a few farmers such as Jim McCulcheon, Homewood, Manitoba; Bob McNabb, Minnedosa, Manitoba; John and Shirley Bennett, Biggar, Saskatchewan; Lucien and Herve Lepage, Montmartre, Saskatchewan; Gerry Willerth, Indian Head, Saskatchewan; Ike and Rod Lanier, Lethbridge, Alberta; and Murray Sankey, Veteran, Alberta, adopted conservation tillage systems in the late 1970s. Lindwall and Larson (2010) interviewed the above farmers and reported the following. First, all interviewed indicated that despite the limited designs of equipment and the high price of glyphosate, growing a crop under conservation tillage system was profitable. Second, all experienced a significant improvement in their soil quality. Third, most early adopters reported facing social challenges, if they were not cultivating the soil while neighbours were busy doing so and sustaining the tillage culture in their community.

Social Challenges

The social challenges that early adopters of conservation tillage technology were facing occurred because the former technology was not only a crop production system, but also an integral part of the farming culture. Tylor (1871) defines culture as the "complex whole which includes knowledge, beliefs, art, morals, law, customs, and any other capabilities and habits acquired by man as a member of society" (p: 4). Based on this definition, traditional tillage is an adaptive culture in the sense that it is historically acquired by farmers through socialization into farm life, and rests on the belief that tilling the land is needed to aerate the soil, improve soil structure, control plant diseases, insects, and weeds, and facilitate a finely tilled seedbed.

As part of a culture, traditional tillage contributed to the collective identity of the farmer. This collective identity, which denotes the type of a farmer who is socially and culturally belongs to, provides the farmer with two values, technical and social. Technically, tilling the soil is the fundamental first task in producing a crop and providing a living for farmers. Socially, the performance of the tillage task, which is shared and recognized by others in the farmer's society, is determined by the feedback from the community. The farmer who has his land tilled with no weeds, no stones, no trash, and cultivator furrows, wins a prize, gains prestige, and enjoys feelings of self–esteem. Thus, the introduction of any alternative technology must also be able to provide farmers with equally potent collective identity. During the 1970s and 1980s, the conservation tillage system, based on the belief that tilling the soil is not necessary to produce a crop, was perceived by many farmers as incompatible with their sociocultural values and beliefs, and thus, with their collective identity as farmers (Carter, 1994; Rogers, 1995). Therefore, by adopting this system a farmer needed to deviate from his collective identity and endure a social cost. This cost reduced a farmer benefit from adopting the new technology.

To increase public awareness of soil degradation issues during the 1970s, Dr. Don Rennie, soil scientist and then the Dean of Agriculture at the University of Saskatchewan, took a controversial stand against the practice of traditional tillage and warned of the long-term effects of this practice in increasing risks of soil erosion, salinity, and organic-matter depletion. He indicated that summerfallow, "is perhaps the most singular mismanagement practice that has been in vogue since this country was opened up" (Fairbairn, 1984, p: 30). Although Dr. Don Rennie was able to attract the attention of some farmers, he met with considerable resistance from others (Fulton and Sonntag, 2010). According to Fairbairn "when Dr. Rennie became so outspoken in the 1970s, a tempestuous conference debated his views - featuring many farmers and other traditionalists who, Rennie felt, were acting like inquisitors at a heresy trial" (Fairbairn, 1984, p: 30). Dr. Rennie concluded that the "summerfallow habit" was a practice that "dies hard" (Fairbairn, 1984).

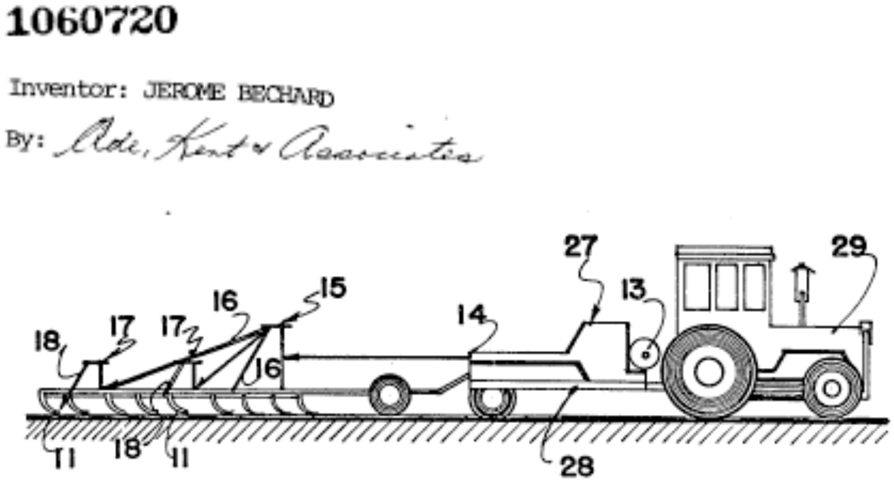
The Development of Air-Seeders

By the late 1970s, Saskatchewan farm implement manufacturers had found a great deal of interest in developing and manufacturing seeding equipment. During the 1990s – 2000s, they became leaders in the production of world class one-pass, low-soil-disturbance air-seeders, which have been exported around the world (Government of Saskatchewan, 2003).

The concept of seeding using forced air was not born on the Prairies. This technology had been used in countries such as Australia and Germany, but had not been widely used on the Prairies before the contribution of Saskatchewan manufacturers in its development. Jerome Bechard, a Saskatchewan innovative farmer, developed the first air-seeder in Western Canada in 1969. In 1979, Bechard acquired a Canadian patent numbered 1060720 and titled "Air Seeding System" (Figure 2.8). Bechard' s invention is described as follows:

> The system is designed to be used in conjunction with conventional tillage equipment such as one–way discers, deep tillage chisel ploughs, field cultivators and the like and can be utilized to plant seed and/or apply fertilizer, herbicides or both. It consists of a separate wheeled trailer carrying the weight of the seed, fertilizer, herbicides and the like thereby eliminating any weight change from the seeding machine The seed or granular chemicals are entrained in air stream and conveyed by headers and conduits to the seeding boots or spouts. Each component is metered from a tank by an upwardly inclined auger assembly driven by a variable speed orbital motor, and deposited into the air stream carried by a main conduit. (Canadian Intellectual Property Office, 2012).

Figure 2.8: Jerome Bechard air-seeder Attached to Cultivator



Source: Canadian Intellectual Property Office (2012)

In the late 1970s, Bourgault Industry Ltd of St. Brieux, Saskatchewan acquired the Jerome Bechard system. In 1980, Bourgault manufactured its first air-seeder, Model 138, which was described by Bourgault as follows:

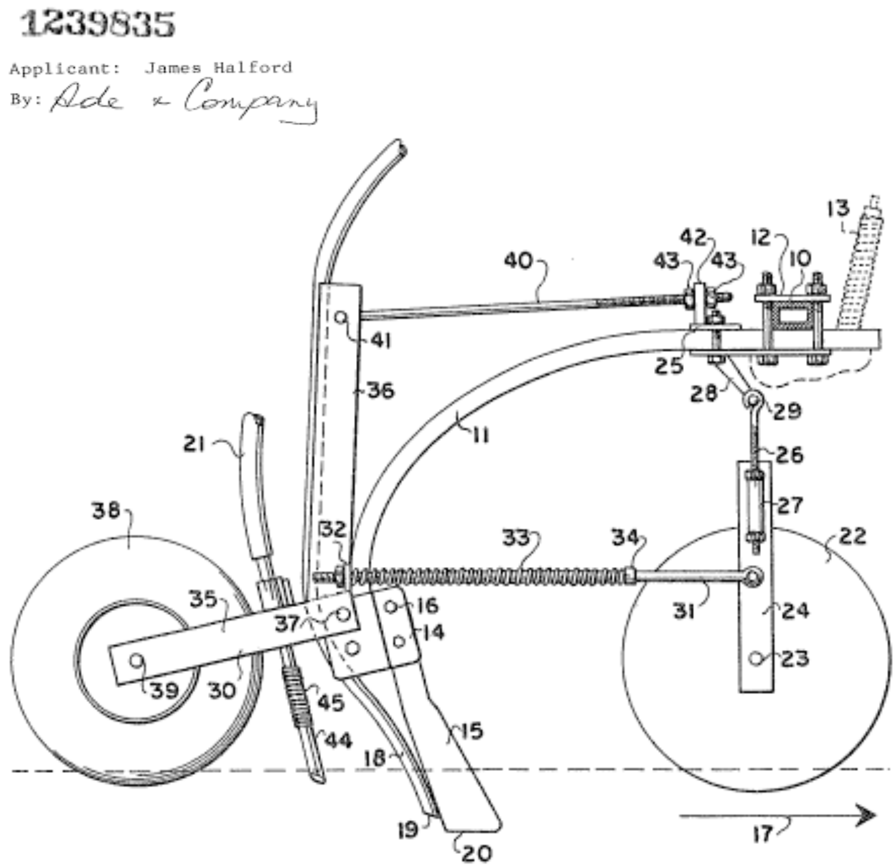
> The first air-seeder to be towed behind the cultivator, giving the operator an unobstructed view of all of the shanks. The Model 138 air-seeder could quickly be disconnected, freeing the cultivator for other fieldwork. This concept of a tow behind unit has served as the model for virtually all of the air-seeders currently being produced throughout the world (Bourgault Industries website–History, p: 2).

Other Saskatchewan companies like Pride Industries, Leon's Manufacturing, Friggstad Manufacturing (purchased by Flexi Coil in 1984), Flexi–Coil, and Morris Industries, were also busy developing large seed drills from their existing cultivator. Although these companies developed a number of air-seeders specialized for Prairie conditions and combined seeding and tillage into single operation, their machines, which include the cultivators equipped with sweeps, expanded the high–disturbance direct seeding options. In 1983, James Halford (ConservaPak/John Deere), a farmer from Indian Head, Saskatchewan developed his own one-pass, low-soil-disturbance air-seeder. In 1988 and 1989, Halford acquired Canadian patents numbered 1239835 and 1263060, and titled "Seed/Fertilizer Placement System for Minimum Tillage Application" and "Packer Wheel Arrangement" for his inventions, respectively. Halford's 1988 invention is described as follows:

> Apparatus for seed and fertilizer placement in the ground comprises a knife followed immediately by a first tube for depositing fertilizer and a second tube spaced there from for depositing the seed. The second tube can be adjusted horizontally and vertically and particularly to a position scraping the side of the furrow formed by the knife to deposit the seed at the side. A packer wheel mounted on the same support as the second tube follows the second tube and runs in the furrow to press down soil over the seed and fertilizer. The packer wheel is rotationally molded from polyethylene (Figure 2.9) (Canadian Intellectual Property Office, 2012).

By the late 1990s, Conserva Pak/John Deere and other companies such as Seed Hawk Inc. located in Langbank, and Seed Master located in Emerald Park, Saskatchewan, were able to produce and export a large number of low-soil-disturbance air-seeder designs that provided accurate depth, fertilizer placement, and packing (McInnis, 2004).

Figure 2.9: James Halford Low Disturbance air-seeder



Source: Canadian Intellectual Property Office (2012)

There were two important organizations that served the Saskatchewan farm implement manufacturing industry during this period of seeding equipment developments. The Prairie Implement Manufactures Association (PIMA) was formed in 1970 to provide programs to inform, educate, share skills, and facilitate communication among its members. The other important organization, Prairie Agricultural Machinery Institute (PAMI) was an applied research, development, and testing association formed in 1971 to facilitate communication among manufacturers and farmers and to provide them with: design, development, manufacturing, and assessment of equipment and components services (The Encyclopedia of Saskatchewan).

The Driving Forces Behind the Adoption of Conservation Tillage

In the 1980s, soil degradation, aggravated by drought, could no longer be ignored on the Prairies. This problem prompted calls to increase efforts to raise public awareness of the impact of traditional tillage practices on soil quality. Three publications contributed significantly to understanding the importance of soil degradation in Canada. "Land Depletion and Soil Conservation Issues on the Canadian Prairies" by the PFRA (1983) brought together, for the first time, the available scientific data on soil erosion and estimated an annual soil loss of 277 Mt for the Prairies. "Soil at Risk: Canada's Eroding Future" by Senator Herb Sparrow (1984) alerted readers that the future of the Canadian Prairies was at risk because of soil degradation. "Will the Bounty End? : The Uncertain Future of Canada's Food Supply" by Garry Fairbairn (1984) indicated that the abundance of agriculture and low food price that Canadian consumers enjoyed were at the cost of soil loss.

In the 1980s, the concern about the cost of soil degradation drove several researchers to assess this cost on the Prairies. The PFRA (1983), Dumanski et al. (1986), and Van Kooten et al. (1989) estimated the annual cost of soil erosion on the Prairies at $239 million, between $155 and $271, and between $35.7 and $453.3 million, respectively. Rennie (1986) estimated the annual cost of land degradation resulting from the use of traditional tillage practices (summerfallow and invasive cultivation practices) at $429.2, $560, and $43.7 million in Alberta, Saskatchewan, and

Manitoba, respectively.

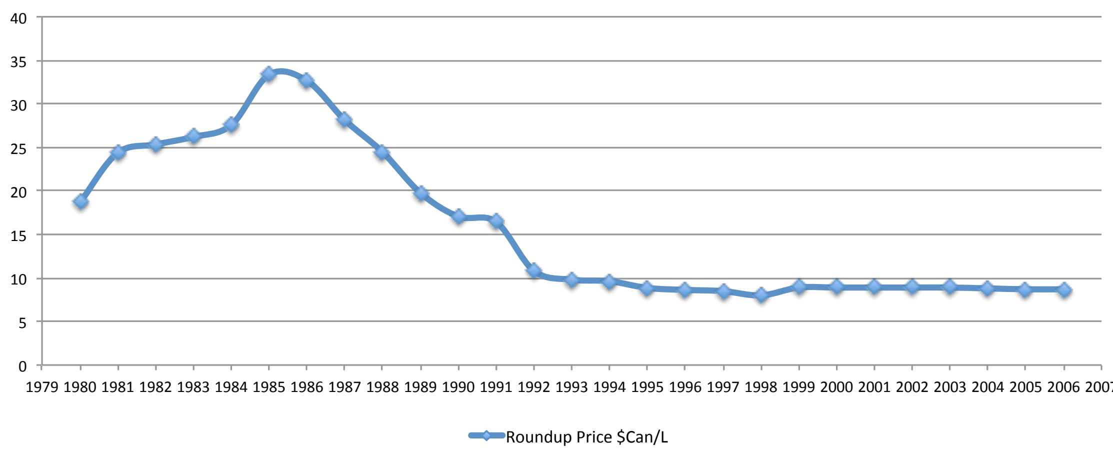
Despite the fact that the above studies on soil loss increased farmers' understanding of the impact of traditional tillage on soil quality, economic, social and technical complexity factors were regarded as deterrents to the adoption of conservation tillage during the 1980s. Economic studies on the Prairies (e.g., Malhi et al., 1988; Smith et al., 1996; Zentner and Lindwall, 1978 and 1982; Zentner et al., 1991 and 1992) indicated that reducing or eliminating tillage to prepare a seedbed and control weeds when moving to conservation tillage reduced the cost of machinery service, which in turn decreased the costs of labour and fuel, and increased the cost of herbicide. According to these studies, during the 1970s and 1980s, the high cost of herbicide glyphosate outweighed the cost advantage of machinery, labour, and fuel and was considered a barrier to the adoption of conservation tillage on the Prairies.

Other studies (e.g., Carter, 1994; Campbell et al., 2002) indicated that the adoption of conservation tillage system was not only limited by the perceived low profitability. Factors such as the complexity of this innovation and the incompatibility of this innovation with farmers' sociocultural values and beliefs were also regarded as deterrents to the adoption of conservation systems on the Prairies.

To deal with the social and technical-complexity problems, conservation tillage associations such as Alberta Conservation Tillage Society, the Manitoba–North Dakota Zero Tillage Farmers Association, the Prairie Farm Rehabilitation Administration (PFRA)–Soil and Water Conservation Branch, Soil Conservation Council of Canada, Saskatchewan Soil Conservation Association (SSCA), Saskatchewan government–Save Our Soils programs, Wheatland Conservation Area (soil conservation clubs formed by farmers in southwestern Saskatchewan), and Alberta Reduced Tillage Linkages were established on the Prairies during the 1980s and 1990s. These associations played an important role in promoting the benefits of conservation tillage systems, responding to farmers' questions, providing technical assistance for effective use of conservation tillage technology, and offering social and moral support (Conservation Technology Information Centre, 2009).

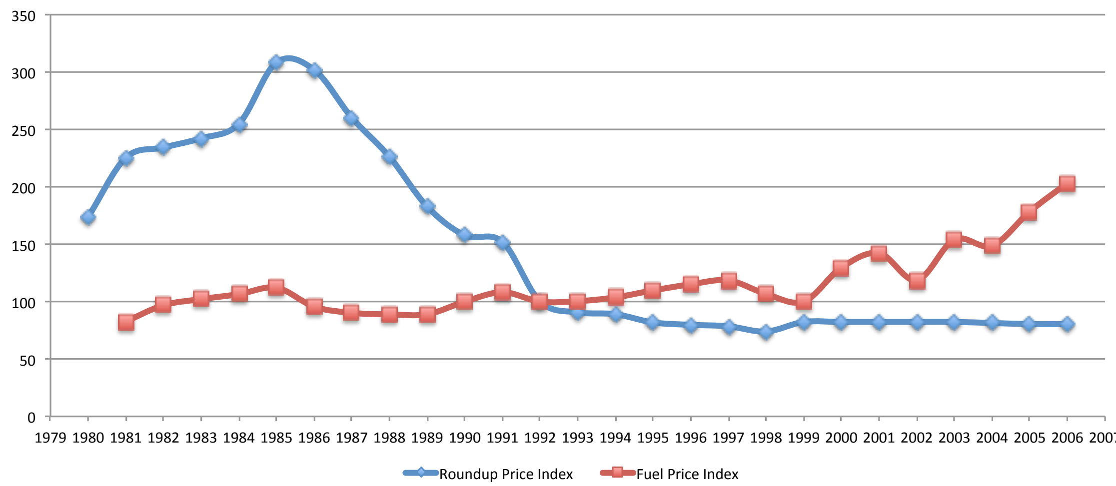
During the 1990s, four economic factors influenced the adoption of conservation tillage systems on the Prairies. First, Saskatchewan farm implement manufacturers improved the zero tillage seeding equipment and technology (e.g., the improvement in the air-seeder technology). Second, although the Roundup patent expired in 2001, Monsanto started to decrease the price of this herbicide in 1985 (Gray 2010). Figure 2.10 shows that the price of Roundup decreased from $33/L in 1985 to $8/L in 1998. Third, the interest rate on borrowed capital decreased, and consequently reduced the cost of investment in new machinery. The interest rate decreased from 13% in 1989 to 7% in 1999 (Saskatchewan Ministry of Agriculture–Farm Machinery, 1990, 2000). Fourth, the price of fuel increased and, thus, increased the cost of operation under traditional tillage (Figure 2.11). Previous studies (e.g., Blomert et al., 1997; Lafond, 1993; Nagy, 1997; Sonntag et al., 1997; Zentner et al., 1999) indicated that the increase in the price of fuel and the decrease in the price of Roundup improved the conservation tillage system profitability and influenced its adoption on the Prairies during the 1990s. The continuous decrease in the price of Roundup relative to the price of fuel made operations that use lots of fuel (e.g., summerfallow and tillage) more expensive to those that do not use lots of tillage (e.g., zero tillage), which in turn can be expected to cause farmers to switch their operations to the least costly option. Figure 2.11 shows that, except for the years 1998 and 1999, the price of fuel continued to increase, while, except for the year 1999, the price of Roundup continued to decrease during the 1990s.

Figure 2.10: Roundup Price in Canada (1980–2006)



Source: Kawal (1993); Statisitics Canada, Farm inputs, selected average prices (1992-1999); and Alberta Agriculture and Rural Development, Alberta Average Farm Input Prices (2000-2006)

Figure 2.11: Roundup Price Index and Fuel Price Index in Canada (1980–2006) (Index, 1992=100)



Sources: Statistics Canada, Farm Input Selected Average Prices (1992-1999); Government of Saskatchewan, Agriculture Statistics Database, Farm Input Price Index (1981-2006); Alberta Agriculture and Rural Development, Alberta Average Farm Input Prices (2000-2006); and Kowal (1993)

2.3 Summary

This chapter identified the historical factors behind the development and adoption of the conservation tillage innovation in the Canadian Prairies between the 1930s and 1990s. A summary of these factors is presented in Table 2.1.

During the 1930s and 1940s, intensive tillage combined with periods of severe drought and a number of dust storms contributed to soil degradation on the Prairies. Soil scientists, such as W. S. Chepil and Sidney Barnes, confirmed that tillage should be kept to a bare minimum, land should only be worked to control weeds, and trash should be kept on the surface to prevent soil degradation (Gray, 1978). In 1935, the federal government established the PFRA that worked together with experimental farms, universities and farmers to combat land degradation and develop more sustainable agriculture practices. The result of these co-operative efforts was the development of trash-cover, ploughless fallow and strip farming practices using one-way discers, duckfoot cultivators, the Morris rod weeder, and the wide-blade cultivator.

During the 1950s and early 1970s, the move toward larger farms and wider equipment made trash and strip farming practices inconvenient. During this period, the first herbicide for broad-spectrum weed control, paraquat, and no-till drill equipment by Allis–Chalmers (US) were introduced on the Prairies. These two factors provided farmers with the necessary components to produce a crop under a low-disturbance, direct-seeding system. However, the high price and inadequate control of paraquat, and the cost and limited success of no-till drills were regarded as deterrents to the adoption of this system on the Prairies. In addition, policy factors such as the Canadian Wheat Board delivery quota system and Lower Inventories for Tomorrow (LIFT) program encouraged farmers to convert seeded areas to summerfallow using tillage practices.

During the early 1970s and 1990s, soil degradation problems increased the efforts to find proper equipment, herbicide, and new crop varieties for conservation tillage on the Prairies. By the late 1970s, conservation tillage started to take shape after the introduction of the herbicide glyphosate by Monsanto, development of commercial no-till drills by Versatile-Noble, Haybuster, and air-seeder attached to cultivator by Jerome Bechard, and development of new crop varieties such as canola by Dr. Downey at the AAFC, Saskatoon, and Dr. Stefansson at the University of Manitoba and pulses by Dr. Slinkard at the CDC, University of Saskatchewan.

Despite the fact that conservation tillage was available to farmers by the late 1970s, economic, social, and technical-complexity factors were regarded as deterrents to its adoption during the 1980s. Replacing or eliminating tillage to prepare a seedbed and replacing tillage by glyphosate to control weeds when moving to conservation tillage reduced machinery operations and increased herbicide requirements. The decrease in machinery operations in turn reduced labour and fuel requirements. During the 1970s and 1980s, the high cost of glyphosate outweighed the cost advantage of machinery, labour, and fuel and was regarded as a barrier to the adoption of conservation tillage on the Prairies (Malhi et al., 1988; Zentner and Lindwall, 1982; Zentner et al., 1991).

During the 1980s and 1990s, conservation tillage associations were established on the Prairies to deal with social and technical-complexity problems farmers might face when adopting conservation tillage. In addition, factors such as the development of a one-pass, low-soil-disturbance air-seeder by James Halford, decrease in the price of glyphosate, reduction in the interest rate on machinery investment and increase in the price of fuel influenced the adoption of conservation tillage on the Prairies during the 1990s (Blomert et al., 1997; Lafond, 1993; Nagy, 1997; Sonntag et al., 1997; Zentner et al., 1999).

As farmers adopted the conservation tillage technology and found that it worked, other farmers became convinced of its workability and profitability. And as more farmers adopted the technology, the more socially acceptable it became.

Table 2.1: A Summary of the Factors Behind the Development and Adoption of the Conservation Tillage Innovation in the Canadian Prairies

The 1930s – 1940s: The Early Development of Reduced Tillage

- Periods of severe drought and a number of dust storms contributed to soil degradation on the Prairies
- Soil scientists, such as W. S. Chepil and Sidney Barnes, confirmed that tillage should be kept to a bare minimum, land should only be worked to control weeds, and trash should be kept on the surface to prevent soil degradation
- In 1935, the federal government established the PFRA that worked together with experimental farms, universities, and farmers to combat land degradation and develop more sustainable agriculture practices
- The result of the co-operative efforts was the development of trash-cover, ploughless fallow and strip farming practices using one-way discers, duckfoot cultivators, the Morris rod weeder, and the wide-blade cultivator
- The Great Depression in the 1930s prevented farmers from investing in new sustainable agriculture practices that replace tillage culture

The 1950s to Early 1970s: The Initial Trial of Low Disturbance Direct Seeding

- The move toward larger farms and wider equipment made trash and strip farming practices inconvenient
- The first herbicide for broad–spectrum weed control, paraquat, and no-till drill equipment by Allis Chalmers were introduced on the Prairies
- The high price and inadequate control of paraquat, and the cost and limited success of no–till drills were regarded as deterrents to the adoption of conservation tillage system on the Prairies
- Policies such as the Canadian Wheat Board delivery quota system and Lower Inventories for Tomorrow (LIFT) program encouraged farmers to convert seeded areas to summerfallow using tillage practices

Continued . . .

Table 2.1 (Continued)

The Early 1970s to the 1990s: The Driving Forces behind the Development and Adoption of Conservation Tillage System on the Prairies

- In 1973, the market for grain received a dramatic shock after the entry of the Soviet Union in the market for grain for the first time, resulting in a substantial increase in grain prices
- Intensive tillage combined with severe drought resulted in more damage to soil quality in the 1970s and 1980s
- In 1974, Monsanto Company introduced the broad–spectrum herbicide glyphosate under the trade name Roundup at a high price
- Advances in crop breeding resulted in the introduction of new varieties of oilseeds and pulses that could be used in rotation with cereal crops on the Prairies
- During the 1970s, Ben Dyck at the AAFC, Swift Current stimulated the development of commercial no-till drills by Versatile–Noble, Haybuster and other manufacturers
- With the introduction of glyphosate, new alternative crops, and the improvement of direct seeding equipment (i.e., disc drill and hoe drill) conservation tillage technology began to take shape and was adopted by some farmers by the end of the 1970s
- In 1979, Jerome Bechard developed the first air-seeder attached to a cultivator on the Prairies
- In 1983, James Halford developed the first low-disturbance air-seeder on the Prairies
- During the 1980s and 1990s, conservation tillage associations were established on the Prairies to deal with social and technical-complexity problems that farmers might face when adoption conservation tillage
- During the 1990s, the advances in conservation tillage equipment, the decrease in the price of glyphosate, the reduction in the interest rate on machinery investment, and the increase in the price of fuel influenced the adoption of conservation tillage on the Prairies

Chapter 3

The Equilibrium Displacement Model

3.1 Introduction

The production of a crop under traditional tillage (TT) and zero tillage (ZT) varies in terms of methods of weed control and seeding operations. Under TT, preparing a seedbed is achieved by tillage and controlling weeds is achieved by tillage and herbicide spraying operations. Under ZT, preparing a seedbed is not required and controlling weeds is attained by herbicide spraying operations. Seeding under ZT requires the use of a specific implement such as a drill no-till and air-seeder. The switch from TT to ZT technology, therefore, removes the need for tillage equipment (i.e., cultivator, harrows and rock picker), requires the investment in a new type of seeder, increases the need of herbicide and reduces machinery operations. The reduction in machinery operations in turn decreases labour and fuel requirements.

For an industry that uses land, machinery, herbicide, labour, fuel, and other variable inputs (e.g., fertilizer and seeds) to produce a crop, the changes in machinery, herbicide, labour, and fuel requirements when moving to ZT not only affect the quantities used and prices of these inputs, but also of other inputs in production via the change in the production function, the impacts of the supply and demand elasticities of output and inputs, and the impact of the elasticity of substitution between inputs. The changes in the quantities and prices of inputs affect the welfare of all input suppliers in the industry.

This chapter presents an equilibrium displacement model that will be used in chapter 4 to estimate the impact of the switch from TT to ZT technology on agricultural input suppliers in the spring wheat industry. The model assumes that the move to ZT technology represents a shock to the equilibrium system. This shock is modelled by changing the efficiency and/or the price of the affected production factors. The change in the efficiency of inputs is treated by modifying the production function using the specification of the factor–augmenting technical change approach. The change in the price of inputs is treated by shifting the corresponding input supply functions.

This chapter is structured as follows. Section two reviews the literature on the equilibrium displacement model and presents the contribution of this study. The third section introduces the equilibrium displacement model.

3.2 Methodology Background

The model developed in this study is built on previous work by Hicks (1932), Muth (1964), and Floyd (1965). Hicks (1932) used a log–linear model to investigate issues in labour economics. An important subsequent paper to Hick's study was the analysis of housing and urban land economics by Muth (1964). The Muth model is a single–output, two–input system in which the impact of various exogenous shocks (e.g., factor–neutral technological change, bias technical change, and shifts in input supply and output demand schedules) on endogenous variables (i.e., prices and quantities of output and inputs) can be determined. In 1965, John Floyd developed a model similar to Muth's to analyze the impact of agricultural policies on endogenous variables in a vertical system.

Recent studies have applied the Hicks–Muth–Floyd model to estimate the market equilibrium implications of a technological change. Alston and Scobie (1983), in a comment on Freebairn, Davis and Edwards (1982), applied the Muth model with one agricultural output and two inputs (agricultural and marketing) to technical change in agriculture to show how the assumption of fixed-proportions between agricultural and other marketing inputs could mislead the estimation of the distribution of research benefits among factors of production.

Mullen, Wohlgenant, and Farris (1988) used the approach to build a two–output (beef and by-products), two–input (agricultural and marketing) model to estimate the distribution of the research benefits among factors of production where the biased technical change is treated as a downward shift in the supply function of the relative inputs. The result of their analysis indicated that cattle producers could receive an increase in their surplus by 57% to 72% if input substitution occured. Mullen, Alston, and Wohlgenant (1989) extended the approach to build a one–output (wool top), three–input (Australian and competing nations' raw wool, and processing inputs) dual model where the technical change in inputs is treated as biased technological change and modelled as a downward shift in the relative input supply function. The authors indicated that the return to the industry from different types of input research were sensitive to the degree of the elasticity of substitution among inputs. Holloway (1989) expanded the one–stage Muth model to build a two–stage (processing and distribution) model to compare the distribution of benefits from research at the production or processing sectors versus promotional effort at the distribution level. The result of his comparative statics indicated that the benefits at the farm level depend crucially on the research at the marketing level and on the degree of substitution between factors of production.

One contribution of the present study is that it reformulates the Hicks–Muth–Floyd mechanism of technical change by using the specification of factor-augmenting technical change approach. The specification of factor–augmenting technical change assumes that the aggregate production function is a functional relationship between the quantity of aggregate output and the quantities of inputs measured in efficiency units rather than actual units. Under this specification, the technology change is incorporated into the production function by adjusting the actual (physical) measures of input quantities (Binswanger, 1974; David and Klundert, 1965; Lianos, 1971; Sato, 1970).

Under the factor-augmenting technical change approach, the relationship between effective and actual quantities of factor i is donated by $X_i^* = A_i X_i$, where A_i is the parameter of input–augmenting technical change for input i, and X_i and X_i^* are the actual (physical) and effective quantities of input i, respectively (Binswanger, 1974;

Martin and Alston, 1994, 1997). When technical change results in a decrease in the actual quantity of input i (i.e., less quantity of input i is needed to produce a given level of output), the index A_i increases. For example, consider an output Y that is produced by using 1 unit of input X, $X = 1$. Define the initial values as $A = 1$, so that $X^* = X = 1$. If the technical change results in a decrease in the actual (physical) quantity of input X by 0.2 unit (i.e., $X = 0.8$) to produce the same level of output Y, and in order for the $X^* = AX$ relationship to hold, A should increase by 0.25 (i.e., $A = 1.25$). A positive change in the value of A_i is treated as an increase in the efficiency of input i. Similarly, when technical change results in an increase in the quantity needed of input i to produce a given level of output, the index A_i decreases. In this case, the change in the value of A_i is negative and is mathematically equivalent to a decrease in the efficiency of input i.

3.3 The Equilibrium Displacement Model

The equilibrium displacement model presented in this study consists of developing a single–output, six–input production system. The model is converted into elasticity form to determine the impact of various exogenous shocks as a result of the change in the technology (i.e., change in the efficiency and price of the production factors) on the endogenous variables (i.e., the equilibrium prices and quantities of output and inputs) in the system. A translog production function (TPF) is used to convert the system into elasticity form. The translog production function is a logarithmic Taylor series expansion to the second degree of any unknown twice-differentiable production function around input quantities. For this type of production function the elasticity of substitution between factors of production can take any arbitrary value.[1]

An equilibrium model, where output supply is represented in terms of an aggregate production function and the related factor demand and supply functions, is described by equations (1) to (14). The model assumes that output, Y, is produced by using the following inputs: land, X_1; machinery service, X_2; other variable inputs (e.g., seed, fertilizer), X_3; farm owned labour, X_4; fuel, X_5; and herbicide, X_6.[2] The model assumes a competitive industry in both output and input markets. Farmers are assumed to maximize their profit and produce a homogenous output product.

The equilibrium displacement model captures the aggregate behaviour at the industry level. The micro-foundations of this model at the farmer level are as follows: farmers are price takers when they make their decisions on how much output to produce and inputs to purchase; farmers operate in a free entry and exit market; farm operators earn zero profit; and farmers only earn rent on the inputs that they own, namely labour and land.

[1]A translog production function is given by: $lnY = lnv_0 + \sum_i v_i lnX_i^* + \frac{1}{2}\sum_i \sum_j \gamma_{ij} lnX_i^* lnX_j^*$. If the part after the double summation is equal to zero, the production function is a Cobb–Douglas. Therefore, the terms in the double summation are seen as adjustment to the Cobb–Douglas function which change the elasticity of substitution from one to any arbitrary value (Binswanger, 1974).

[2]The model can be generated to examine n–factor of production.

Output Demand	$Y = h(P)$	(1)
Production Function	$Y = f(X_1^*, X_2^*, X_3^*, X_4^*, X_5^*, X_6^*)$	(2)
Factor Demand of Land	$P_1 = Pf_1$	(3)
Factor Demand of Machinery Service	$P_2 = Pf_2$	(4)
Factor Demand of Other Variable Inputs	$P_3 = Pf_3$	(5)
Factor Demand of Farm-owned labour	$P_4 = Pf_4$	(6)
Factor Demand of Fuel	$P_5 = Pf_5$	(7)
Factor Demand of Herbicide	$P_6 = Pf_6$	(8)
Supply of Land	$X_1 = g_1(P_1, B_1)$	(9)
Supply of Machinery Service	$X_2 = g_2(P_2, B_2)$	(10)
Supply of Other Variable Inputs	$X_3 = g_3(P_3, B_3)$	(11)
Supply of Farm-0wned Labour	$X_4 = g_4(P_4, B_4)$	(12)
Supply of Fuel	$X_5 = g_5(P_5, B_5)$	(13)
Supply of Herbicide	$X_6 = g_6(P_3, B_6)$	(14)

Equation (1) is the demand for the industry output, where Y and P are the quantity and price of output, respectively. Equation (2) is the production function, where Y is a single homogeneous output produced by the use of six inputs (X_1, X_2, X_3, X_4, X_5, and X_6), with the corresponding factor–augmenting coefficients (A_1, A_2, A_3, A_4, A_5, and A_6). The relationship between the effective and the actual quantities of production factors is donated by $X_i^* = A_i X_i$ for all $i = 1, 2, 3, 4, 5, 6$. Equations (3) to (8) are the demand of factors X_i, with the assumption that each factor is paid the value of its marginal products. The term f_i is the marginal product of input $i = 1, 2, 3, 4, 5, 6$. Equations (9) to (14) are the factor supply curves facing the industry in which B_i

is an exogenous shifter of the supply curve of input X_i. The endogenous variables in the model are industry output, Y; the amounts of the six inputs used in production by the industry (X_1, X_2, X_3, X_4, X_5, and X_6); the price per unit of the output, P; and the factor prices (P_1, P_2, P_3, P_4, P_5, and P_6).

Assuming that the technology results in a small shift from the initial equilibrium, the changes in quantities and prices can be approximated by totally differentiating equations (1) to (14) and converting them into percentage change and elasticity form.

3.3.1 Converting the Equilibrium Displacement Model into Percentage Change and Elasticity Form

Output Demand

$$Y = h(P) \tag{1}$$

By totally differentiating equation (1), and dividing by Y we get

$$\frac{dY}{Y} = h_p \frac{dP}{Y} \tag{1'}$$

where $h_p = \frac{\partial Y}{\partial P}$. Since the own-price elasticity of the demand is given by: $\eta = -\frac{\partial Y}{\partial P}\frac{P}{Y}$, $h_p = -\eta \frac{Y}{P}$. Substituting h_p into equation ($1'$), the percentage change in the quantity demanded is given by

$$E(Y) = -\eta E(P) \tag{15}$$

Production Function

$$Y = f(X_1^*, X_2^*, X_3^*, X_4^*, X_5^*, X_6^*) = f(A_1X_1, A_2X_2, A_3X_3, A_4X_4, A_5X_5, A_6X_6) \qquad (2)$$

By totally differentiate equation (2) we get

$$dY = \sum_i \left(\frac{\partial Y}{\partial A_iX_i}\frac{\partial A_iX_i}{\partial X_i}\right)dX_i + \left(\frac{\partial Y}{\partial A_iX_i}\frac{\partial A_iX_i}{\partial A_i}\right)dA_i \qquad i = 1,2,3,4,5,6 \qquad (2')$$

Since,

$$\frac{\partial Y}{\partial A_i} = X_i\frac{\partial Y}{\partial A_iX_i}; \qquad \frac{\partial Y}{\partial X_i} = A_i\frac{\partial Y}{\partial A_iX_i}; \qquad \text{and} \qquad \frac{\partial Y}{\partial A_i} = \frac{X_i}{A_i}\frac{\partial Y}{\partial X_i}$$

Thus,

$$\frac{\partial Y}{\partial A_i}\frac{A_i}{Y} = \frac{\partial Y}{\partial X_i}\frac{X_i}{Y} = \frac{A_iX_i}{Y}\frac{\partial Y}{\partial A_iX_i} = K_i \qquad \text{for all } i = 1,2,3,4,5,6$$

where K_i is the relative factor share of inputs $i = 1,2,3,4,5$ and 6. Substituting these relations into equation $(2')$, and dividing by Y, the percentage change in the production function is given by

$$E(Y) = \sum_{i=1}^{6} K_iE(X_i) + \sum_{i=1}^{6} K_iE(A_i) \qquad (16)$$

Factor Demand Equations

The translog production function with six inputs can be written in logarithmic form as

$$lnY = lnv_0 + \sum_i v_i lnX_i^* + \frac{1}{2}\sum_i \sum_j \gamma_{ij} lnX_i^* lnX_j^* \qquad (b)$$

The terms v_0, v_i, and γ_{ij} are the parameters of the production function, where v_0, v_i and γ_{ij} are constant parameters and are donated by

$$v_i = \frac{\partial lny}{\partial lnX_i}; \qquad \gamma_{ii} = \frac{\partial^2 lny}{\partial lnX_i^2}; \qquad \text{and} \qquad \gamma_{ij} = \frac{\partial^2 lny}{\partial lnX_i \partial lnX_j}$$

If the part after the double summation in equation (b) is equal to zero, then the production function is a Cobb–Douglas. Therefore, the terms in the double summation are seen as adjustment to the Cobb–Douglas function which changes the elasticity of substitution from a unit value (Binswanger, 1974). Assuming linear homogeneity, equation (b) must satisfy the following conditions:

$i)$ symmetry constraint: $\gamma_{ij} = \gamma_{ji}$ for all i, j, $i \neq j$

$ii)$ $\sum_i v_i = 1$; $\sum_i \gamma_{ij} = 0$; $\sum_j \gamma_{ij} = 0$ for all i, j

Converting the factor of demand equations into percentage change and elasticity form is achieved in the following three steps:

1) *Converting the* γ_{ij} *Coefficient into Elasticity Form*

Using the Allen partial elasticity of substitution σ_{ij}, and the (i) and (ii) conditions for the linear homogeneous production function, the γ_{ij} coefficients can be converted into elasticity form.

$$\begin{aligned}\gamma_{ij} &= \frac{\partial^2 lny}{\partial lnX_i lnX_j} \\ &= X_j \frac{\partial}{\partial X_i}\Big(\frac{\partial y}{\partial X_i} - \frac{X_i}{Y}\Big) \\ &= X_j\Big(f_{ij}\frac{X_i}{Y} - \frac{X_i}{Y^2}f_i f_j\Big) \qquad (c)\end{aligned}$$

where $f_i = \frac{\partial Y}{\partial X_i}$; $\quad f_j = \frac{\partial Y}{\partial X_j}$; and $\quad f_{ij} = \frac{\partial^2 y}{\partial X_i \partial X_j}$

Substituting the Allen partial elasticity of substitution for the linear homogeneous production function, $\sigma_{ij} = \frac{f_i f_j}{Y f_{ij}}$, and the relative factor share, $K_i = f_i \frac{X_i}{Y}$ into equation (c), the coefficient γ_{ij} is equal to

$$\gamma_{ij} = \frac{K_i K_j}{\sigma_{ij}} - K_i K_j \qquad \text{for all} \qquad i \neq j \qquad (d)$$

Using the condition $\sum_i \gamma_{ij} = 0$ for the linear homogenous production function, the parameter γ_{ii} is given by

$$\gamma_{ii} = -\sum_i \Big(\frac{K_i K_j}{\sigma_{ij}} - K_i K_j\Big) \qquad \text{for all} \qquad i = 1, 2, 3, 4, 5, 6 \qquad (e)$$

where

$$K_i = \frac{P_i X_i}{PY} = \frac{X_i}{Y} f_i \qquad \text{is the relative factor share for factor } i$$

In the case of six factors of production: $\gamma_{12} = \gamma_{21} = \frac{K_1 K_2}{\sigma_{12}} - K_1 K_2$; $\gamma_{13} = \gamma_{31} =$

$\frac{K_1K_3}{\sigma_{13}} - K_1K_3$; $\gamma_{14} = \gamma_{41} = \frac{K_1K_4}{\sigma_{14}} - K_1K_4$; $\gamma_{15} = \gamma_{51} = \frac{K_1K_5}{\sigma_{15}} - K_1K_5$; $\gamma_{16} = \gamma_{61} = \frac{K_1K_6}{\sigma_{16}} - K_1K_6$; and $\gamma_{11} = -\left(\left(\frac{K_1K_2}{\sigma_{12}} - K_1K_2\right) + \left(\frac{K_1K_3}{\sigma_{13}} - K_1K_3\right) + \left(\frac{K_1K_4}{\sigma_{14}} - K_1K_4\right) + \left(\frac{K_1K_5}{\sigma_{15}} - K_1K_5\right) + \left(\frac{K_1K_6}{\sigma_{16}} - K_1K_6\right)\right)$

2) *Differentiating the Translog Production Function*

The first order derivative of the TPF with respect of lnX_i^* is given by[3]

$$\frac{\partial lnY}{\partial lnX_i^*} = v_i + \sum_j \gamma_{ij} lnX_j^* \qquad (f)$$

By using the following relations

- $\frac{\partial Y}{\partial X_i} = \frac{P_i}{P}$
- $\frac{\partial Y}{\partial X_i^*} = \frac{\partial y}{\partial X_i}\frac{\partial X_i}{\partial X_i^*} = \frac{1}{A_i}\frac{P_i}{P}$
- $\frac{\partial lnY}{\partial lnX_i^*} = \frac{\partial Y}{\partial X_i^*}\frac{X_i^*}{Y} = \frac{1}{A_i}\frac{P_i}{P}\frac{A_iX_i}{Y} = \frac{P_i}{P}\frac{X_i}{Y} = K_i$

equation (f) is equal to

$$\frac{\partial lnY}{\partial lnX_i^*} = v_i + \sum_j \gamma_{ij} lnX_j^* = K_i \qquad (f')$$

Totally differentiate equation (f')

[3] The derivation of the translog cost function can be found in Binswanger (1974).

$$dK_i = \sum_{j=1}^{6} \gamma_{ij} dlnX_j^* = \sum_{j=1}^{6} \gamma_{ij}(dlnX_j + dlnA_j) \qquad \text{where } i = 1,2,3,4,5,6 \qquad (g)$$

Separating terms and using matrices

$$\begin{bmatrix} dK_1 \\ dK_2 \\ dK_3 \\ dK_4 \\ dK_5 \\ dK_6 \end{bmatrix} = \begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} & \gamma_{26} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} & \gamma_{36} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} & \gamma_{46} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} & \gamma_{56} \\ \gamma_{61} & \gamma_{62} & \gamma_{63} & \gamma_{64} & \gamma_{65} & \gamma_{66} \end{bmatrix} \times \begin{bmatrix} dlnX_1 \\ dlnX_2 \\ dlnX_3 \\ dlnX_4 \\ dlnX_5 \\ dlnX_6 \end{bmatrix} +$$

$$\begin{bmatrix} \gamma_{11} & \gamma_{12} & \gamma_{13} & \gamma_{14} & \gamma_{15} & \gamma_{16} \\ \gamma_{21} & \gamma_{22} & \gamma_{23} & \gamma_{24} & \gamma_{25} & \gamma_{26} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} & \gamma_{35} & \gamma_{36} \\ \gamma_{41} & \gamma_{42} & \gamma_{43} & \gamma_{44} & \gamma_{45} & \gamma_{46} \\ \gamma_{51} & \gamma_{52} & \gamma_{53} & \gamma_{54} & \gamma_{55} & \gamma_{56} \\ \gamma_{61} & \gamma_{62} & \gamma_{63} & \gamma_{64} & \gamma_{65} & \gamma_{66} \end{bmatrix} \times \begin{bmatrix} dlnA_1 \\ dlnA_2 \\ dlnA_3 \\ dlnA_4 \\ dlnA_5 \\ dlnA_6 \end{bmatrix} \qquad (g)$$

Because of the linear homogeneity the (g) matrix is not of full rank, this problem can be solved by substituting the following relationships into (g)

- $\gamma_{16} = -\gamma_{11} - \gamma_{12} - \gamma_{13} - \gamma_{14} - \gamma_{15}$

- $\gamma_{26} = -\gamma_{21} - \gamma_{22} - \gamma_{23} - \gamma_{24} - \gamma_{25}$

- $\gamma_{36} = -\gamma_{31} - \gamma_{32} - \gamma_{33} - \gamma_{34} - \gamma_{35}$

- $\gamma_{46} = -\gamma_{41} - \gamma_{42} - \gamma_{43} - \gamma_{44} - \gamma_{45}$

- $\gamma_{56} = -\gamma_{51} - \gamma_{52} - \gamma_{53} - \gamma_{54} - \gamma_{55}$

- $\gamma_{61} = -\gamma_{62} - \gamma_{63} - \gamma_{64} - \gamma_{65} - \gamma_{66}$

3) *Separating and Substituting Terms*

Solving equation (g) for dK_i and dividing by K_i, the share of factor X_1 in percentage form is given by (the shares of factors X_2, X_3, X_4, X_5, and X_6 are solved similarly):

$$\begin{aligned} E(K_1) = {} & \frac{\gamma_{11}}{K_1}(dlnX_1 - dlnX_6) + \frac{\gamma_{12}}{K_1}(dlnX_2 - dlnX_6) + \frac{\gamma_{13}}{K_1}(dlnX_3 - dlnX_6) + \\ & \frac{\gamma_{14}}{K_1}(dlnX_4 - dlnX_6) + \frac{\gamma_{15}}{K_1}(dlnX_5 - dlnX_6) + \frac{\gamma_{11}}{K_1}(dlnA_1 - dlnA_6) + \\ & \frac{\gamma_{12}}{K_1}(dlnA_2 - dlnA_6) + \frac{\gamma_{13}}{K_1}(dlnA_3 - dlnA_6) + \frac{\gamma_{14}}{K_1}(dlnA_4 - dlnA_6) + \\ & \frac{\gamma_{15}}{K_1}(dlnA_5 - dlnA_6) \end{aligned} \tag{h}$$

On the other hand, the percentage change of the market share $K_i = \frac{P_i X_i}{PY}$, $i = 1, 2, 3, 4, 5, 6$ is given by

$$E(K_i) = E(X_i) + E(P_i) - E(P) - E(Y) \tag{i}$$

Substitute $E(Y)$ from equation (16) into equation (i) and then into equations (h), the factor demand equation of factor X_1 is given by (the factor demand equation of factors X_2, X_3, X_4, X_5, and X_6 are solved similarly)

$$
\begin{aligned}
E(P_1) = E(P) &+ \Big(-1 + K_1 + \frac{\gamma_{11}}{K_1}\Big) E(X_1) + \Big(K_2 + \frac{\gamma_{12}}{K_1}\Big) E(X_2) + \Big(K_3 + \frac{\gamma_{13}}{K_1}\Big) E(X_3) \\
&+ \Big(K_4 + \frac{\gamma_{14}}{K_1}\Big) E(X_4) + \Big(K_5 + \frac{\gamma_{15}}{K_1}\Big) E(X_5) + \Big(K_6 + \frac{\gamma_{16}}{K_1}\Big) E(X_6) \\
&+ \Big(K_1 + \frac{\gamma_{11}}{K_1}\Big) E(A_1) + \Big(K_2 + \frac{\gamma_{12}}{K_1}\Big) E(A_2) + \Big(K_3 + \frac{\gamma_{13}}{K_1}\Big) E(A_3) \\
&+ \Big(K_4 + \frac{\gamma_{14}}{K_1}\Big) E(A_4) \Big(K_5 + \frac{\gamma_{15}}{K_1}\Big) E(A_5) + \Big(K_6 + \frac{\gamma_{16}}{K_1}\Big) E(A_6) \qquad \text{(j)}
\end{aligned}
$$

Substituting equations (d) and (e) into equations (j), the factor demand equation of input X_1 in percentage change and elasticity form is given by (the factor demand equation of factors X_2, X_3, X_4, X_5, and X_6 are solved similarly)

$$
\begin{aligned}
E(P_1) = E(P) &- \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} \Big) E(X_1) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} E(X_j) \\
&+ \bigg(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} \Big) \bigg) E(A_1) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} E(A_j) \qquad j \neq 1 \qquad (17)
\end{aligned}
$$

Input Supply Equations

$$X_1 = g_1(P_1, B_1) \qquad (6)$$

By totally differentiating equation (6), and divided by X_1, we get
$\frac{dX_1}{X_1} = g_{X_1}(\frac{dP_1}{X_1}) - g_{B_1}(\frac{dB_1}{X_1})$; where $g_{X_1} = \frac{\partial X_1}{\partial P_1}$ and $g_{B_1} = \frac{\partial X_1}{\partial B_1}$.

$\frac{dX_1}{X_1} = \frac{\partial X_1}{\partial P_1}\frac{P_1}{X_1}\frac{dP_1}{P_1} - \frac{\partial X_1}{\partial P_1}\frac{\partial P_1}{\partial B_1}\frac{P_1}{X_1}\frac{B_1}{P_1}\frac{dB_1}{B_1}$

The percentage change in the supply of input X_1 is given by (the percentage change in the supply of input X_2, X_3, X_4, X_5, and X_6 are solved similarly)

$$E(X_1) = e_1(E(P_1) - E(B_1)) \tag{23}$$

where $E(B_1)$ is exogenous shift parameter that expresses equilibrium displacement relative to the initial equilibrium and the term $e_1 = \frac{\partial X_1}{\partial P_1}\frac{P_1}{X_1}$ is the input supply elasticity of X_1. The elasticity term associated with $E(B_1)$ is assumed to take a value of 1 and is expressed as relative change in the price of factor X_1 (e.g., setting $E(B_1)$ equal to 0.01 indicates a 1% increase in the price relative to the initial price of factor X_1) (Mullen, Alston, and Wohlgenant, 1989).

The Equilibrium Displacement Model in Percentage Change and Elasticity Form is given by

$$E(Y) = -\eta E(P) \tag{15}$$

$$E(Y) = \sum_{i=1}^{6} K_i E(X_i) + \sum_{i=1}^{6} K_i E(A_i) \tag{16}$$

$$\begin{aligned} E(P_1) = E(P) &- \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}}\Big) E(X_1) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} E(X_j) \\ &+ \left(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}}\Big)\right) E(A_1) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{1j}} E(A_j) \qquad j \neq 1 \end{aligned} \tag{17}$$

$$\begin{aligned} E(P_2) = E(P) &- \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{2j}}\Big) E(X_2) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{2j}} E(X_j) \\ &+ \left(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{2j}}\Big)\right) E(A_2) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{2j}} E(A_j) \qquad j \neq 2 \end{aligned} \tag{18}$$

$$\begin{aligned} E(P_3) = E(P) &- \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{3j}}\Big) E(X_3) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{3j}} E(X_j) \\ &+ \left(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{3j}}\Big)\right) E(A_3) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{3j}} E(A_j) \qquad j \neq 3 \end{aligned} \tag{19}$$

$$
\begin{aligned}
E(P_4) &= E(P) - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{4j}}\Big) E(X_4) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{4j}} E(X_j) \\
&\quad + \bigg(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{4j}}\Big)\bigg) E(A_4) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{4j}} E(A_j) \qquad j \neq 4 \qquad (20)
\end{aligned}
$$

$$
\begin{aligned}
E(P_5) &= E(P) - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{5j}}\Big) E(X_5) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{5j}} E(X_j) \\
&\quad + \bigg(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{5j}}\Big)\bigg) E(A_5) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{5j}} E(A_j) \qquad j \neq 5 \qquad (21)
\end{aligned}
$$

$$
\begin{aligned}
E(P_6) &= E(P) - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{6j}}\Big) E(X_6) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{6j}} E(X_j) \\
&\quad + \bigg(1 - \Big(\sum_{j=1}^{6} \frac{K_j}{\sigma_{6j}}\Big)\bigg) E(A_6) + \sum_{j=1}^{6} \frac{K_j}{\sigma_{6j}} E(A_j) \qquad j \neq 6 \qquad (22)
\end{aligned}
$$

$$E(X_1) = e_1(E(P_1) - E(B_1)) \qquad (23)$$

$$E(X_2) = e_2(E(P_2) - E(B_2)) \qquad (24)$$

$$E(X_3) = e_3(E(P_3) - E(B_3)) \qquad (25)$$

$$E(X_4) = e_4(E(P_4) - E(B_4)) \qquad (26)$$

$$E(X_5) = e_5(E(P_5) - E(B_5)) \qquad (27)$$

$$E(X_6) = e_6(E(P_6) - E(B_6)) \qquad (28)$$

where E denotes the percentage change (e.g., $E(P) = dP/P$), η is the absolute value of the own–price elasticity of product demand, K_i is the cost share of factor i ($K_i = \frac{P_i X_i}{PY} = \frac{X_i}{Y} f_i$, and $\sum_{i=1}^{6} K_i = 1$), σ_{ij} is the Allen partial elasticity of substitution in production between inputs i and j for a linear homogenous production function ($\sigma_{ij} = \frac{f_i f_j}{Y f_{ij}},\ i \neq j$), and e_i is the elasticity of supply of factor i. The system of fourteen equations (15) to (28) has fourteen endogenous variables (the relative changes in prices and quantities, $(E(Y), E(P), E(X_i)$, and $E(P_i)$ for all $i = 1, 2, 3, 4, 5, 6)$, twenty eight parameters (η; K_i; e_i for all $i = 1, 2, 3, 4, 5, 6$; and $n(n-1)/2$ elasticities of substitution), and twelve exogenous variables ($E(A_i)$; and $E(B_i)$; i=1,2,3,4,5,6). The exogenous parameters ($E(A_i)$, and $E(B_i)$) represent equilibrium displacements relative to an initial equilibrium. It is assumed that for small changes from the initial equilibrium, the market parameters, η, e_i, K_i, and σ_{ij}, remain constant.

Equations (15) to (28) are solved for the endogenous variables by using the matrix algebra approach. The first step in the solution is to write the model in matrix form as $MZ = G$ (the system of equations (15) to (28) in matrix form is found in Appendix A); where M is a 14×14 matrix of parameters, Z is the vector of the fourteen endogenous variables, and G is the sum of the exogenous shocks vectors. The second step is to solve for the vector of the endogenous variables, $Z = M^{-1}G$; where M^{-1} is the inverse of the 14×14 matrix of parameters.

Assuming that equations (15) to (28) are local approximations to unknown supply and demand functions in the form of linear logarithmic differentials and elasticities, and that these functions shift in parallel as a result of the change in the exogenous variables, the change in the economic surplus to factors of production sectors, ΔPS_i for $i = 1, 2, 3, 4, 5, 6$, can be calculated in terms of the estimated changes in factor and product prices and quantities by using the following equations (Alston, 1991; Mullen, Alston, and Wohlgenant, 1989):

$$\Delta PS_1 = P_1 X_1 [E(P_1) - E(B_1)][1 + 0.5E(X_1)] \tag{29}$$

$$\Delta PS_2 = P_2 X_2 [E(P_2) - E(B_2)][1 + 0.5E(X_2)] \tag{30}$$

$$\Delta PS_3 = P_3 X_3 [E(P_3) - E(B_3)][1 + 0.5E(X_3)] \tag{31}$$

$$\Delta PS_4 = P_4 X_4 [E(P_4) - E(B_4)][1 + 0.5E(X_4)] \tag{32}$$

$$\Delta PS_5 = P_5 X_5 [E(P_5) - E(B_5)][1 + 0.5E(X_5)] \tag{33}$$

$$\Delta PS_6 = P_6 X_6 [E(P_6) - E(B_6)][1 + 0.5E(X_6)] \tag{34}$$

$$\Delta TS = \sum_i \Delta PS_i \tag{35}$$

Chapter 4

The Welfare Implication of the Switch from Traditional to Zero Tillage Technology: The Vertical Market Analysis

4.1 Introduction

Using the equilibrium displacement model presented in Chapter 3, this section examines the impact of the switch from TT to ZT technology on different agricultural input suppliers in the spring wheat industry on the Prairies in 1989. The model can be applied to any crop. The spring wheat industry is chosen because of its importance on the Prairies during the 1980s.

In this study, an output, Y, is produced by using six factors of production, X_1, X_2, X_3, X_4, X_5, and X_6; where Y is spring wheat; X_1 is land; X_2 is machinery service; X_3 is other variable inputs (e.g., seed, fertilizer, and hired labour); X_4 is farm–owned labour; X_5 is fuel; and X_6 is herbicide.

Machinery service is defined as the process that uses agricultural equipment to provide farmers with the service of preparing land, seeding, spraying, harvesting, drying, pulling, moving crops, etc. Farmers are assumed to receive the same machinery service but pay different costs for this service under TT and ZT systems. In this study, machinery service costs are given by the sum of the machinery overhead (depreciation, investment and insurance) and repair costs.

Producing a crop under TT and ZT systems is assumed to vary by method of weed control and seeding operation. Controlling weeds and preparing a seedbed under the TT system is assumed to be achieved by two fall tillage and two spring tillage operations using tillage equipment, and one fall and two spring herbicide spraying operations using a sprayer. Preparing a seedbed is not required under the ZT system. Controlling weeds under the ZT system is assumed to be achieved by two fall and three spring herbicide spraying operations using a sprayer. It is assumed that plots are planted by using a drill disc press under the TT system and a drill no-till under the ZT system. The differences in crop production systems by field operations and machinery passes are presented in Table 4.1.

Table 4.1: The Differences in Crop Production Systems by Field Operations and Machinery Passes

Season	Field Operation			Machinery Passes	
		TT	**ZT**	**TT**	**ZT**
Fall	Tillage to control weed	Yes	No	2	0
	Spray for winter annual weed	No	Yes	0	1
	Post-emergent herbicide	Yes	Yes	1	1
	Harvest	Yes	Yes	1	1
Spring	Tillage to control weed & prepare seedbed	Yes	No	2	0
	Pre-seeding burn-off with glyphosate	No	Yes	0	1
	Pre-emergent herbicide	Yes	Yes	1	1
	Post-emergent herbicide	Yes	Yes	1	1
	Seeding & banding fertilizer	Yes	Yes	1	1
Summer	Crop monitoring	Yes	Yes	–	–

Source: University of Saskatchewan (U of S): Guide to Farm Practice in Saskatchewan, 1985, and Nagy, 1997

This chapter is structured as follows: Section two presents a representative farm that is going to be used to estimate the changes in machinery service, labour, fuel, and herbicide requirements under TT and ZT systems. Section three describes the impact of the change in the affected inputs requirements under TT and ZT on the equilibrium displacement model. Section four presents the values of the equilibrium displacement model parameters. Section five calculates the changes in the machinery service, labour, fuel and herbicides requirements under TT and ZT and presents the values of the exogenous variables in the equilibrium displacement model. Section six estimates the changes in quantities and prices at the output and inputs levels when moving to ZT technology and uses these results to calculate the changes in the welfare of agriculture input suppliers in the spring wheat industry in 1989. Section seven performs a sensitivity analysis on the specified point value of the equilibrium displacement model parameters. Section eight examines the change in the welfare of input suppliers in the spring wheat industry when moving to ZT technology through different scenarios. Finally, section nine summarizes the main findings and concludes the chapter.

4.2 A Representative Farm

The change in the method of controlling weeds and seeding operations when moving to ZT are expected to affect machinery service, labour, fuel and herbicide inputs requirements. A representative farm of average size and soil moisture (i.e., a medium size farm of 1800 acres operating in the Dark–Brown soil type), growing spring wheat on stubble in 1989, is used to estimate these changes under TT and ZT systems.

A representative farm is important since machinery service, hours of operation, and labour requirements change with farm size, and herbicide requirements and crop yields vary with soil type. For instance, machinery purchase cost is 27% higher for a large-sized farm compared to a medium-sized farm under both TT and ZT systems (Nagy 1997). Under ZT technology, growing spring wheat on stubble requires 25% more herbicide in the Dark–Brown and Black soil zones than in the Brown soil zone, while, under TT technology, growing wheat on stubble requires 30% to 40% more herbicide in the Dark–Brown and Black soil zones than in the Brown soil zone (Saskatchewan Agriculture and Food, Economics Branch, Farm Management 1989, 1999, and 2010). Averaged across 1989–2010, spring wheat on stubble yields did not vary with the type of tillage practices. However, yields by soil zones ranged from 20 to 26 bushels/acre in the brown soil, 26 to 32 bushels/acre in the Dark–Brown soil, and 30 to 38 bushels/acre in the Black soil zone (Saskatchewan Agriculture and Food, Economics Branch, Farm Management 1989, 1999, and 2010).[1]

A more precise way to examine the impact of the switch from TT to ZT on farm suppliers is to capture the soil–type heterogeneity on the Prairies (i.e., Black, Dark–Brown, and Brown types of soil). The equilibrium displacement model was used to analyze the impact of this switch by using data for each soil type. The results revealed no significant differences in the return to input suppliers operating in different soil types. Thus, to keep the analysis simple, a farm operating in the Dark–Brown soil is used in this study as a representative farm for all of the Prairies.[2]

For an average farm in 1989, the difference in crop production systems by machinery types, purchase prices and hours of use are presented in Table 4.2. Table 4.2 shows that the move to ZT decreases machinery total purchased price by around \$16000 and reduces the number of hours of machinery use by 1010.[3] These two fac-

[1]According to Lafond et al. (1992) the effects of crop rotations on yields are insignificant, thus these effects are not taken into consideration in this analysis.

[2]Note that if soil–type heterogeneity is considered in the analysis, a representative farm in each of the Black, Dark–Brown, and Brown soil type should be designed. In this case, the aggregate output supply would be given by $Y = \sum S_j Y_j$, where j = Black, Dark–Brown, and Brown soil type, S_j is the share of output Y in soil type j and Y_j is j's output supply; the input i's demand in soil type j would be given by P_i^j, where $i = 1, 2, 3, 4, 5$ and 6; and the input i's supply by $X_i = \sum R_i^j X_i^j$, where R_i^j is the share of input i in soil-type j and X_i^j is input i's supply in soil type j. In this case, the equilibrium displacement model is described by 47 equations with 47 endogenous variables (Y, Y_j , X_i, X_i^j, P and P_i^j) where P and P_i^j are the output price and the price of input i in soil–type j, respectively; all other variables are as defined before.

[3]Nagy (1997) compared the purchase price of equipment under TT and ZT system for a 1840-acre farm at 1996 prices and found that although the purchase price of seeding equipment under ZT system (i.e., air-seeder) was higher than under TT system (i.e., press drill), eliminating the need for tillage equipment under ZT system reduced machinery total purchase price by around \$15,000.

tors are expected to reduce machinery service cost, including machinery overhead (depreciation, investment and insurance) and repair costs. In addition, the decrease in the number of hours of machinery operations reduces labour and fuel requirements under ZT.

Replacing tillage by herbicide to control weeds when moving to ZT results in an addition of new components to the herbicide recipe (e.g., glyphosate) which increases the need for herbicide and may increase its cost, if the prices of the new components increase the average cost per unit of herbicide.

Table 4.2: Machinery Service Requirement, Purchase Price and Annual Hours of Use for an Average Farm in 1989

Machinery	Desc.	Purchased Cost in 1989 Dollars		Hours of Use[a]	
		TT	ZT	TT	ZT
Tillage Equipment					
Heavy Duty Cultivator (D)[b]	36 foot	22,100	–	390	–
Harrows (D)	60 foot	7,370	–	60	–
Rock Picker (D)	fork type	3,850	–	60	–
Seeding Equipment					
Drill Disc Press (D)	30 foot	41,000	–	150	–
Drill No–till Disc (D)	30 foot	–	60,600	–	150
Chemicals Applicators					
Granular Herbicide Appl (D)	46 foot	6,000	–	90	–
Sprayer PT 500 gal (D)	60 foot	7,130	–	200	–
Sprayer PT 800 gal (D)	80 foot	–	10,900	–	250
Harvest Equipment					
Grain Auger Out (P)[c]	7″× 33	2,800	2,800	16	16
Grain Auger In (D)	10″× 60	4,610	4,610	8	8
Combine (P)	240 HP	120,000	120,000	164	164
Combine PU Header (P)	14 foot	13,500	13,500		
Combine Flex Header (P)	20 foot	13,500	13,500		
Combine Ridged Header (P)	24 foot	11,500	11,500		
Swather SP DSA (P)	22 foot	43,800	43,800	190	190
Grain Dryer Continuous (P)	500 bu/hr	30,000	30,000	97	97
Vehicles					
Pickup (P)	1/2 ton	16,600	16,600	200	200
Grain Truck (P)	210 HP	30,000	30,000	300	300
Tractors					
Primary (P)	250 HP	116,600	116,600	860	400
Secondary (P)	120 HP	60,000	60,000		
Total	–	$550,360	$534,410	2785	1775

Sources: Saskatchewan Ministry of Agriculture–Farm Machinery (1990) and Nagy (1997)
[a] Machines' hours of use are calculated in Appendix B; [b] D: drawn equipment; and
[c] P: powered equipment

4.3 The Displacement of the Equilibrium Model

The changes in machinery service, labour, fuel and herbicide requirements when moving to ZT shock the system of equations (15)–(28) as follows. First, the decrease in machinery service cost results in a downward shift in the supply curve of this input. This case is treated in equation (24) by assigning a positive value to the exogenous variable $E(B_2)$ equal to the percentage decrease in the cost of machinery service. Second, the decrease in the use of farm-owned labour results in an increase in the efficiency of this input. This case is treated in equations (16)–(22) by giving a positive value to the exogenous variable $E(A_4)$ equal to the percentage decrease in the quantity required of labour to produce a given level of output Y. Similarly, the changes in fuel and herbicide requirements are treated in equations (16)–(22) by assigning a positive value to the variable $E(A_5)$ and a negative value to the variable $E(A_6)$, indicating a decrease in the quantity needed of fuel and an increase in the quantity needed of herbicide, respectively. Finally, the increase (decrease) in the cost of herbicide shocks equation (28) by giving the variable $E(B_6)$ a negative (positive) value, indicating an upward (downward) shift in the supply curve of herbicide.

The exogenous variables $E(A_1), E(A_2)$, and $E(A_3)$ in equations (16)–(22) are assumed to be equal to zero when moving to ZT, indicating no change in the efficiency of land, machinery, and other variable inputs, respectively. In addition, $E(B_1), E(B_3), E(B_4)$, and $E(B_5)$ in equations (23) and (25)–(28) are assumed to equal zero when moving to ZT, indicating no change in the cost per unit of land, other variable inputs, farm-owned labour, and fuel, respectively. In section 8, the assumption of no change in land efficiency is relaxed in the long run and treated by assigning a positive value to the variable $E(A_1)$. Table 4.3 represents the expected changes in the efficiency and cost of the production factors as a result of the switch from TT to ZT technology.

Table 4.3: Expected Change in the Efficiencies and Costs of the Production Factors as a Result of the Switch from TT to ZT Technology

Factor Name	Exogenous Variables Expected % Change in the:		Description
	Efficiency $E(A)$	Cost/Unit $E(B)$	
Land	$E(A_1) = 0$	$E(B_1) = 0$	No change in the efficiency (in the short run) and cost
Machinery Service	$E(A_2) = 0$	$E(B_2) < 0$	No change in the efficiency and decrease in the cost
Other Variable Inputs	$E(A_3) = 0$	$E(B_3) = 0$	No change in the efficiency and cost
Farm-owned Labour	$E(A_4) > 0$	$E(B_4) = 0$	Increase in the efficiency and no change in the cost
Fuel	$E(A_5) > 0$	$E(B_5) = 0$	Increase in the efficiency and no change in the cost
Herbicide	$E(A_6) < 0$	$E(B_6) > 0; < 0;$ or $= 0$	Decrease in the efficiency and increase, decease, or no change in the cost

Equations (16)–(22) show that the increase in the efficiency of farm-owned labour ($E(A_4) > 0$) results in an upward shift in the production function curve (see Figure 4.1 a), a downward shift in the demand curve of farm-owned labour (labour-saving technical change), and an upward shift in the demand curves of the other inputs – land, machinery, other variable inputs, fuel, and herbicide (see Figure 4.1 c & d). Labour-saving technical change decreases the marginal physical product of labour which in turn shifts down the demand curve of this input and increases the marginal rate of technical substitution (MRTS) between the other inputs and labour (Hicks, 1932).[4] At a constant quantity of output, the decrease in the marginal physical product of labour increases the marginal physical product of the other inputs and results in an increase in the demand curve of these inputs Muth (1964) (see Figure 4.1 b).[5] The increase in the efficiency of fuel, $E(A_5 > 0)$, and the decrease in the efficiency of herbicide, $E(A_6 < 0)$ are interpreted similarly. Equation (24) shows that the decrease in the cost of machinery service ($E(B_2) < 0$) results in a downward shift in the supply curve of this input. This case is illustrated in Figure 4.2. The change in the cost of herbicide $E(B_6)$ is interpreted similarly.

The shifts in the production function curve and input demand and supply curves as a result of the switch from TT to ZT are expected to change the quantities and prices of output and all inputs in production. The sign and magnitude of these changes depend on the value of the exogenous variables $E(A_4)$, $E(A_5)$, $E(A_6)$, $E(B_2)$,

[4]Hicks' definition of input saving-technical change is as follows: at a constant capital-labour input ratio, technical change is labour-saving, if marginal rate of technical substitution (MRTS) between capital and labour increases. Mathematically, this can be expressed as follows: $\Delta MRTS = -\Delta \frac{dL}{dK} = \Delta \frac{f_K}{f_L} > 0$ where Δ denotes the change and f_K and f_L stand for the marginal physical product of capital and labour, respectively. If technical change results in a downward shift in the demand of labour, f_L decreases and thus, the MRTS increases, indicating a labour–saving technical change (Hicks, 1932).

[5]In the case of two-input (labour and capital), one-output production system, Muth (1964) indicated that since the output quantity is constant (i.e., E(y)=0), a labour–saving technical change not only deceases the marginal physical product of labour, but also increases capital's marginal physical product.

and $E(B_6)$ and the value of the parameters η, e_i, σ_{ij}, and K_i. The parameter values are chosen from estimates developed in previous studies of the Canadian wheat industry and Canadian agriculture and are presented in section 4.4. The exogenous variable values are calculated and are presented in section 4.5.

Figure 4.1: The Displacement of the Equilibrium Model as a Result of the Increase in Labour Efficiency

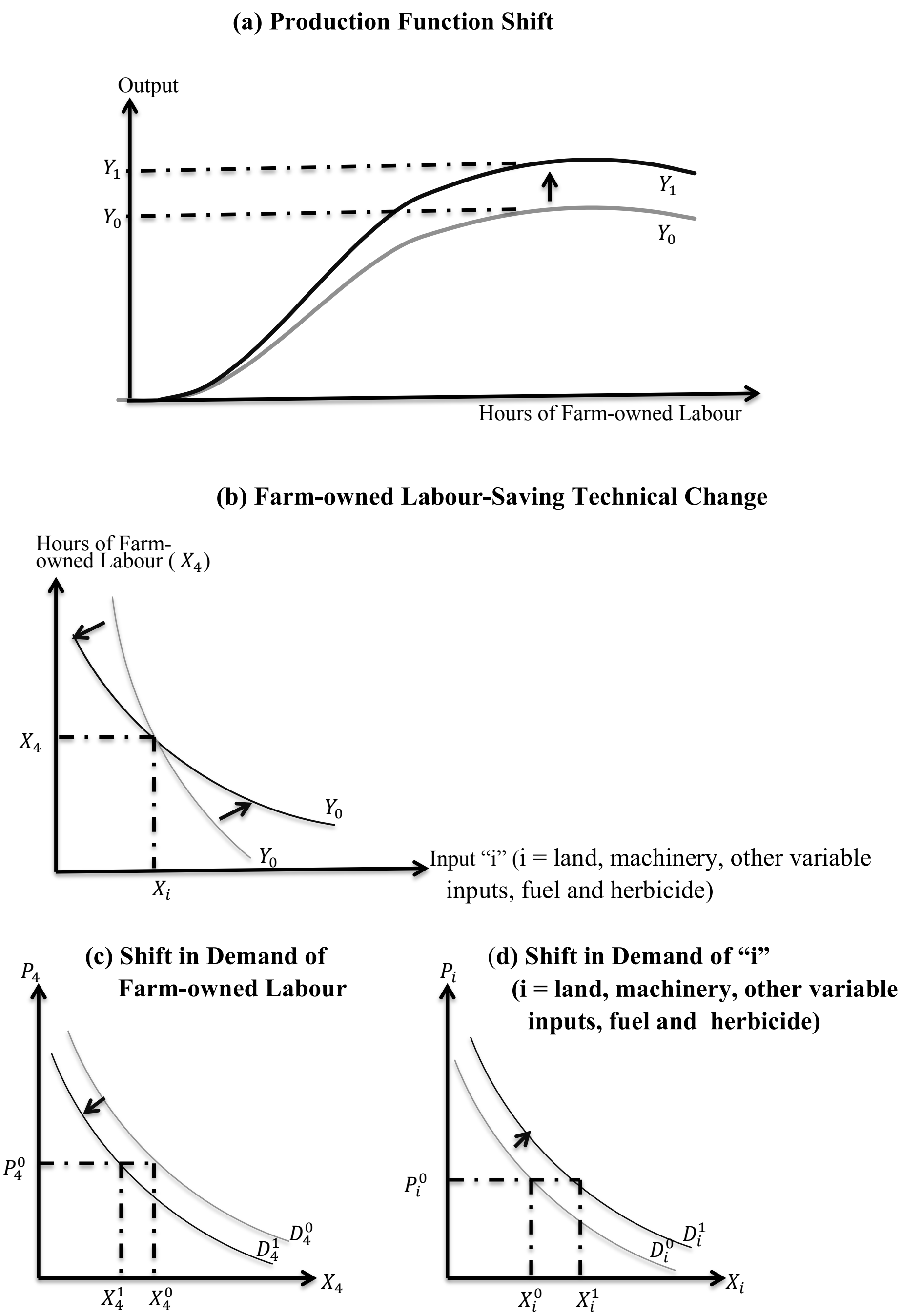
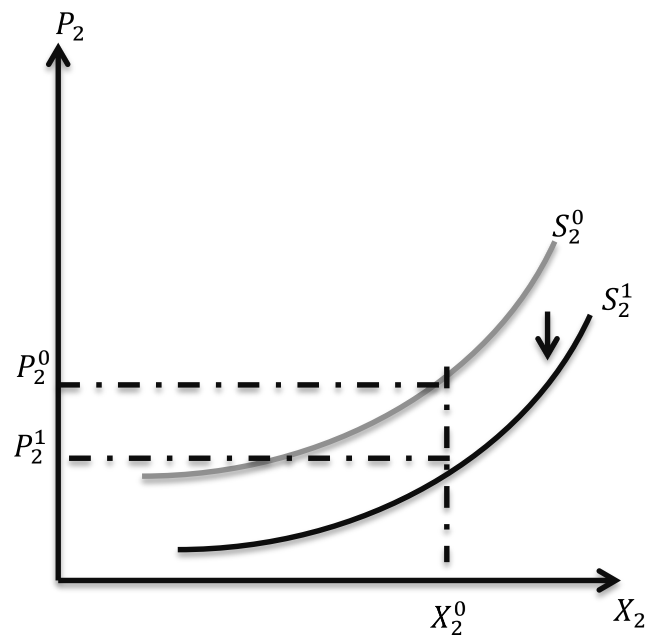


Figure 4.2: The Displacement of the Equilibrium Model as a Result of the Decrease in Machinery Service Price



4.4 The Parameter Values of the Equilibrium Displacement Model

The values of the parameters, K_i, η, σ_{ij}, and e_i are chosen from estimations of previous studies of the Canadian wheat industry and Canadian agriculture and presented below. This study treats machinery service, other variable inputs, fuel, and herbicide as purchased inputs. A summary of the parameter values used in this study is presented in Table 4.6.

Input Cost Shares

This study uses estimates of factor cost shares for the wheat industry provided by Glaze and Schoney (1995) and the Organization for Economic Co–operation and Development (OECD) (2001). The cost share of land is $K_1 = 0.4$, machinery service is $K_2 = 0.3$, other variable inputs is $K_3 = 0.15$, farm–owned labour is $K_4 = 0.04$, fuel is $K_5 = 0.05$, and herbicide is $K_6 = 0.06$.[6]

Elasticity of Demand for Wheat

A study conducted by the Government of Canada (2001) over a five-year period (1994–1998) indicated that, on average, Canada is ranked the world's sixth–largest producer of wheat, preceded, in order of importance, by China, the EU, the US, India, and Russia. Canada exports around 90% of its wheat production, which accounts for about 20% of the world market for wheat exports. With this amount, Canada occupies second place among the world's major wheat–exporter countries, preceded by the US (30%), and followed by the EU (17%), Australia (12%), Argentina (7%), and others (14%)(Government of Canada, 2001).

During the study period, the Canadian Wheat Board (CWB) was the single–desk seller for Canada's wheat in the international market (Government of Canada, 2001). Kraft, Furtan, and Tyrchniewicz (1996) found evidence that Canada could price-discriminate in its higher value markets such as Japan and the UK. However, in the other markets Canada was not able to do so. As a consequence, for the marginal sales, Canada can be thought of as a price taker.

[6]Hired labour cost share of wheat production on the Prairies ranges between 0% to 1% (Glaze and Schoney, 1995; OECD, 2001).

Since at the margin at which Canada is a price taker in the world wheat market, the value of the price demand elasticity for wheat, η, is assumed to be equal to infinity ($\eta = \infty$). Under this assumption, the price of wheat, P, is determined exogenously. The percentage change in the price of output is equal to zero ($E(P) = 0$).

Factor Substitution Elasticities

This paper uses factor substitution elasticities estimated by the OECD (2001). According to the OECD study the elasticity of substitution between land and farm-owned labour is 0.1; the elasticity of substitution between land and purchased inputs is 0.5; the elasticity of substitution between farm-owned labour and purchased inputs is 0.9; and the elasticity of substitution between purchased inputs (machinery service, other variable inputs, fuel, and herbicide) is 0.1 (except for the elasticity of substitution between machinery and fuel which is assumed to be equal to zero). Table 4.4 presents the estimated factor substitution elasticities in previous studies, and the substitution elasticities used in this study.

Factor Supply Elasticities for Canadian Agriculture

Table 4.5 presents values of factor supply elasticities for Canadian agriculture estimated by previous studies. In Table 4.5, estimates of own price elasticities of land supply tend to be low and vary from 0.1 to 0.4. This study uses a supply elasticity of land equal to 0.1.

Estimates of supply elasticities for purchased inputs (machinery service, other variable inputs, fuel, and herbicide) tend to be high and vary between 2 to 2.5

Table 4.4: Factor Substitution Elasticities for Canadian Agriculture

Study	Elasticity of Substitution Between: Land & Own-labour	Land & Purch. Inputs [a]	Owned Labour & Purch. Inputs	Purch. Inputs
Lopez (1980)	0.2	1.0	1.2	–
Islam and Veeman (1980)	0.3	-0.7	1.5	-0.8
Lopez and Tung (1982)	-1.8	1.5	1.4	0.0
Adamowicz (1986)	0.1	-0.1	0.3	0.1
Moschini (1988)	–	–	0.6	0.2
Karagiannis and Furtan (1990)	0.3	0.7	0.3	–
Andrikopoulos and Brox (1992)	1.2	0.5	0.9	–
Toichoa–Buaha and Apland (1996)	–	–	–	0.1
OECD (2001)	0.1	0.5	0.9	0.1
Present Study Elasticity	0.1	0.5	0.9	0.1

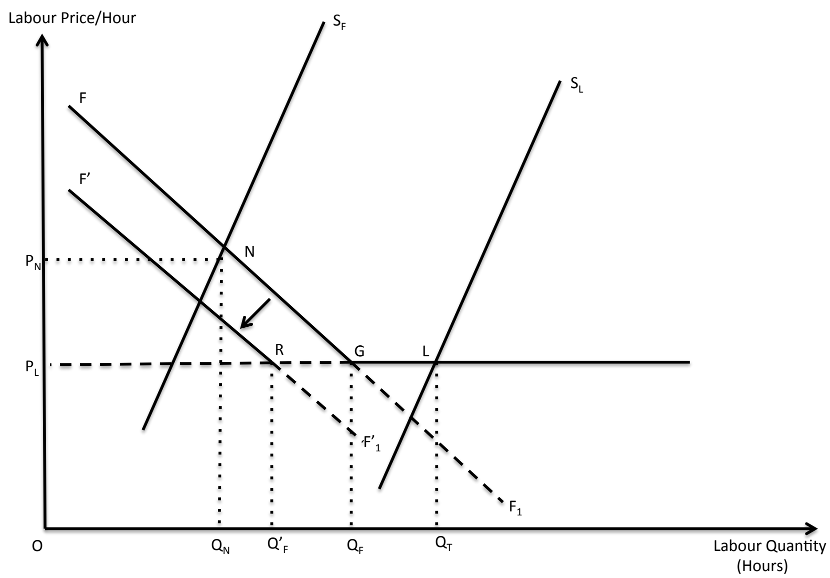
[a] Purchased Inputs = Machinery Service, Other Variable Inputs, Fuel and Herbicide.

(Table 4.5). A supply elasticity of purchased inputs equal to 2.5 is used in this study.

Estimates of the supply elasticities of labour vary in a wide range between 0.12 and 2.7 (Table 4.5). This variation is due to the differences from one study to another in the length of run being considered, and in the broadness of factor "labour" (i.e, farm-owned and hired labour) being estimated, with the tendency of having larger supply elasticity estimation in the long run and for hired labour. For instance, the study by Smit (1978) considered long–run estimation of household labour, and the studies by Burniaux et al (1990) and Sarwar and Fox (1992) considered the estimation of all labour (farm-owned and hired labour). Therefore, these studies arrived at fairly high supply elasticities. However, the studies by Lopez (1984) and the OECD (2001) considered the estimation of household labour in the short–run and they both arrived at low supply elasticities.

If farmers are engaged in off-farm work and the return to the marginal hour of farm work is fixed and equal to the off-farm work rate, then the farm labour supply curve is perfectly elastic at a price equal to the off-farm wage rate (Bollman, 1979).

Figure 4.3: Labour Market Equilibrium with Farm and Off-farm Work



Source: Bollman (1979)

Figure 4.3 illustrates the case when the demand curve for labour in on–farm work, FF_1, is downward–sloping, and the off-farm wage of labour, P_L, which represents the opportunity cost, is fixed (i.e., farmers can work as many hours as they like in off-farm work at a fixed rate). The number of hours worked on–farm is determined by the intersection of FF_1 and P_L curves. If the farmer engages in some off-farm work, the supply curve of labour, S_L, intercepts the opportunity cost curve at L.[7] The total number of hours worked by the farmer is OQ_T where OQ_F hours are worked on-farm

[7] If a farmers are not engaged in off-farm work, the number of hours worked (all on-farm) is determined by the intersection of the demand curve for on-farm labour FF_1 and the labour supply curve S_F in Figure 4.3.

and $Q_F Q_T$ are worked off-farm. When the technological change reduces the hours of work in farming, the demand curve for on-farm labour shifts to the left (from FF_1 to $F'F'_1$), resulting in a decrease in the amount of hours worked on-farm by $Q_F Q'_F$ and an increase in the number of hours worked off–farm by the same amount. The return to the marginal hour of farm work is fixed and equal to the off–farm rate, OP_L (Figure 4.3).

In this study, it is assumed that farmers are engaged in off-farm work. The price of farm-owned labour, P_4, is fixed (the supply elasticity of farm-owned labour is equal to infinity ($e_4 = \infty$) and the percentage change in the price of this input as a result of the technical change is equal to zero ($E(P_4) = 0$).

Table 4.5: Own-price Factor Supply Elasticities for Canadian Agriculture

Study	Land	Owned Labour	Purch. Inputs
Smit (1978)	-	1.50	-
Lopez (1984)	-	0.12	-
Meilke and Weersink (1990)	0.10 to 0.25	-	-
Burniaux el al (1990)	-	2.70	-
Clark and Klein (1992)	0.10 to 0.30	-	-
Sarwar and Fox (1992)	0.10	1.50 to 2.00	2.00
OECD (2001)	0.40	0.40	2.50
Present Study Elasticity	0.1	∞	2.5

Table 4.6: Summary of the Parameter Values

Parameter	Value	Description
Factor Cost Share		Cost share of
K_1	0.40	land
K_2	0.30	machinery service
K_3	0.15	other variable inputs
K_4	0.04	farm–owned labour
K_5	0.05	fuel
K_6	0.06	herbicide
Elasticity of Demand for Wheat		
η	∞	Absolute value of the elasticity of final demand
Factor Supply Elasticity		Elasticity of supply of
e_1	0.1	land
e_2	2.5	machinery service
e_3	2.5	other variable inputs
e_4	∞	farm–owned labour
e_5	2.5	fuel
e_6	2.5	herbicide

Elasticity of Substitution Between Inputs ($\sigma_{ij} = \sigma_{ji}, i \neq j$)

i/j	Land	Machinery	Other Var. Inputs	Labour	Fuel	Herbicide
Land	–	0.5	0.5	0.1	0.5	0.5
Machinery	0.5	–	0.1	0.9	0.0	0.1
Other Var. Inputs	0.5	0.1	–	0.9	0.1	0.1
Labour	0.1	0.9	0.9	–	0.9	0.9
Fuel	0.5	0.0	0.1	0.9	–	0.1
Herbicide	0.5	0.1	0.1	0.9	0.1	–

4.5 The Exogenous Variable Values of the Equilibrium Displacement Model – The Percentage Change in the Efficiency and Price of Inputs

As previously indicated, the switch from TT to ZT technology affects the requirements of the machinery service, herbicide, farm-owned labour and fuel factors (Table 4.3). This section describes and estimates the quantity required of and the price paid for these inputs to produce a final product (spring wheat) under TT and ZT systems for an average farm (i.e., 1800 acres farm in the Dark Brown soil type) growing spring wheat in 1989. Comparing the estimated quantities and prices under both systems, the value of machinery service, $E(B_2)$; farm-owned labour, $E(A_4)$; fuel, $E(A_5)$; and herbicide, $E(A_6)$ and $E(B_6)$, are calculated.

Machinery Service Requirement

The cost of machinery service is defined as the sum of the machinery overhead (depreciation, investment, and insurance) and repair costs and is calculated by using the following formulas:

$$\text{(a)- Depreciation \$/hr} = \frac{\left(\frac{\text{Purchase Price - Salvage Value}}{\text{Years Lifetime}}\right)}{\text{Annual Hours of Use}}$$

$$\text{(b)- Investment \$/hr} = \frac{\left(\frac{\text{Purchase Price + Salvage Value}}{2}\right) \times 13\%}{\text{Annual Hours of Use}}$$

$$\text{(c)- Insurance \$/hr} = \frac{(\text{Purchase Price} \times 1\%)}{\text{Annual Hours of Use}}$$

$$\text{(d)- Repair \$/hr} = \left(\frac{\text{Purchase Price}}{1000}\right) \times \text{Repair Cost Factor}$$

Source: Saskatchewan Ministry of Agriculture: Farm Machinery (1990).

For an average sized-farm in 1989, machinery purchase price and annual hours of use are given in Table 4.2, machinery depreciation lifetime and repair index are presented in Appendix B, the interest rate on machinery investment is given by 13% and the machinery salvage value is assumed to be equal to 10% of the machinery purchase price (Saskatchewan Ministry of Agriculture, 1990).

Using formulas (a)–(d) and the associated values, the differences in the machinery cost are estimated and presented in Table 4.7. Total machinery service cost under the TT system is \$60.59/acre and under the ZT system is \$54.34/acre. The 11% decrease in the machinery service cost under ZT is mainly due to the elimination of tillage equipment and to the lower cost of operating tractors, partially offset by a higher cost of seeding and spraying equipment. Machinery harvest service cost does not change under both systems (Table 4.7).

Table 4.7: Machinery Service Cost under Traditional and Zero Tillage Systems for an Average Farm in 1989

Machinery	Overhead ($)			Repair ($)	Total ($)	($)/Acre
	Depreciation	Investment	Insurance			
Traditional Tillage (TT)						
Tractors	14,449	12,627	1,766	7,852	36,694	20.39
Cultivator HD	1,658	1,580	221	1,896	5,355	2.97
Harrows	338	527	74	119	1,058	0.59
Rock Picker	315	275	39	72	701	0.39
Drill Disc Press	2,460	2,932	410	1,230	7,032	3.91
Granular Herbicide Appl.	360	429	60	203	1,052	0.58
Sprayer 500 gal	1,283	510	71	285	2,150	1.19
Grain Auger Out	140	200	28	18	386	0.21
Grain Auger In	207	330	46	15	598	0.33
Combines	11,888	11,333	1,585	5,537	30,342	16.86
Swather SP	3,584	3,132	438	2,413	9,567	5.31
Grain Dryer	1,500	2,145	300	349	4,294	2.39
Pickup	1,423	1,187	166	412	3,187	1.77
Grain Truck	2,700	2,145	300	1,494	6,639	3.69
Total	**42,305**	**39,351**	**5,504**	**21,895**	**109,054**	**60.59**
Zero Tillage (ZT)						
Tractors	10,961	12,627	1,766	3,652	29,006	16.11
Drill No Till Disc	3,636	4,333	606	1,818	10,393	5.77
Sprayer 800 gal	1,962	779	109	545	3,395	1.89
Grain Auger Out	140	200	28	18	386	0.21
Grain Auger In	207	330	46	15	598	0.33
Combines	11,888	11,333	1,585	5,537	30,342	16.86
Swather SP	3,584	3,132	438	2,413	9,567	5.31
Grain Dryer	1,500	2,145	300	349	4,294	2.39
Pickup	1,423	1,187	166	412	3,187	1.77
Grain Truck	2,700	2,145	300	1,494	6,639	3.69
Total	**38,001**	**38,210**	**5,344**	**16,253**	**97,808**	**54.34**

Farm-owned Labour Requirement

Labour quantity is measured by the number of hours required to perform duties such as operating equipment (i.e., tractor, auger, combine, swather, pickup and grain truck) and other miscellaneous tasks (e.g., management, preparing seeds, mixing fertilizers and herbicides, machinery repair, etc). Hours of machinery operations are presented in Table 4.2, and miscellaneous tasks hours are assumed to be equal to 20% of the total labour hours of machinery operations (C. Nagy, U of S, personal correspondence). Under both TT and ZT systems, labour is charged at $9/hr (Saskatchewan Ministry of Agriculture, 1990). Table 4.8 presents the differences in crop production systems by labour hour requirement and price for an average farm in 1989. Table 4.8 shows that the switch from the TT to the ZT system reduces labour hours by around 550 hours. The 31% saving in labour hours under the ZT system is mainly due to eliminating tillage operations which reduce the hours of labour needed to operate the tractors from 860 to 400 hours (Table 4.8).

Table 4.8: Farm-owned Labour Requirement under Traditional and Zero Tillage Systems for an Average Farm in 1989

Operations	Hours (TT)	Hours (ZT)	Total ($)[a] (TT)	Total ($) (ZT)	($)/Acre (TT)	($)/Acre (ZT)
Tractors	860	400	7,740	3,600	4.30	2.00
Grain Auger Out	16	16	144	144	0.08	0.08
Grain Auger In	8	8	72	72	0.04	0.04
Combines	164	164	1,476	1,476	0.82	0.82
Swather SP	190	190	1,710	1,710	0.95	0.95
Pickup	200	200	1,800	1,800	1.00	1.00
Grain Truck	300	300	2,700	2,700	1.50	1.50
Miscellaneous Tasks[a]	348	256	3,128	2,300	1.74	1.28
Total	**2,086**	**1,534**	**18,770**	**13,802**	**10.43**	**7.67**

[a] Miscellaneous Tasks' hours are equal to 20% of the total labour's hours of machinery operations (C. Nagy, University of Saskatchewan, personal correspondence).

Fuel Requirement

Table 4.9 presents the difference in crop production systems, TT and ZT, by fuel quantity and cost for an average farm in 1989. Fuel types and prices and fuel rate of consumption (per litre) for the powered equipment under study are presented in Appendix B. Using these values, Table 4.9 shows that the switch from TT to ZT technology decreases the amount of fuel/litre required for an average farm by 39%. The saving in fuel quantity/litre is due to the elimination of tillage operations which decreases the hours of use of tractors and, hence, decreases the amount of fuel/litre from around 39.6 thousand litres under the TT system to around 18.4 thousand litres under the ZT system (Table 4.9).

Table 4.9: Fuel Requirement under Traditional and Zero Tillage Systems for an Average Farm in 1989

Operations	Hours (TT)	Hours (ZT)	Liters (TT)	Liters (ZT)	Total ($) (TT)	Total ($) (ZT)	($)/Acre (TT)	($)/Acre (ZT)
Tractor Primary	430	200	27,520	12,800	11,558	5,376	6.42	2.99
Tractor Secondary	430	200	12,040	5,600	5,057	2,352	2.81	1.31
Grain Auger Out	16	16	16	16	8	8	0.00	0.00
Grain Auger In	8	8	11	11	5	5	0.00	0.00
Combines	164	164	5,248	5,248	2,204	2,204	1.22	1.22
Pickup	200	200	2,800	2,800	1,344	1,344	0.75	0.75
Grain Truck	300	300	6,900	6,900	3,312	3,312	1.84	1.84
Swather SP	190	190	2,660	2,660	1,117	1,117	0.62	0.62
Grain Dryer	97	97	7,760	7,760	2,716	2,716	1.51	1.51
Total	**1,835**	**1,375**	**64,955**	**43,795**	**27,322**	**18,434**	**15.18**	**10.24**

Herbicide Requirement

Weed control methods used while the crop is growing (i.e., pre-emergent and post–emerged herbicide spraying methods) are the same under TT and ZT systems (University of Saskatchewan: Guide to Farm Practice in Saskatchewan, 1985). Weeds that are traditionally managed by tillage operations, including some types of winter annual and perennial weeds, are poorly controlled by in-crop herbicide and thus late fall and pre-seeding herbicide applications are required to control those types of weeds under the ZT system (Moyer at al., 1994). Perennial weeds (e.g., quackgrass, and dandelion) can be controlled by using pre-seeding burn-off with glyphosate herbicide in the early spring (Alberta Agriculture, Food and Rural Development, 2004). Winter annual weeds (e.g., stinkweed and flixweed), which germinate in the fall and overwinter, and flower and produce seeds in the spring and summer of the following year, can be controlled in late fall or early spring (pre-seeding). Herbicides such as 2,4–D, MCPA, and glyphosate provide good control for winter annuals in the fall.

2,4–D and MCPA herbicide, which last in the soil for a few weeks, are not registered for pre-seeding weed control because of the possibility of injury to crops, and thus herbicide glyphosate is recommended in the case of early spring control of winter annual weeds (Alberta Agriculture, Food and Rural Development, 1999). Although glyphosate herbicide can control both perennial and winter annual weeds in the spring, one application to control both types cannot be achieved because of the difference in the time of application for optimal control of these types of weeds (Alberta Agriculture, Food and Rural Development, 1999). For this reason and because of the high price of glyphosate in 1989, this study choses herbicides 2,4–D and MCPA to control winter annual weeds in the fall. Herbicide recipes for TT and ZT systems are presented in Table 4.10.

Table 4.10 presents the differences in crop production systems, TT and ZT, by herbicide quantity and price for an average farm in 1989. Table 4.10 shows that the move to ZT system increases the herbicide quantity/litre by 48% and average price/litre by 6.6% (average herbicide price/litre is $9.26 under TT and $9.89 under ZT). The increased use of herbicide is due to the replacement of tillage operations by herbicide (glyphosate, 2,4–D and MCPA) applications to control winter annual and perennial weeds. Most of the herbicide price differences are attributed to the high price of glyphosate in 1989.

Table 4.10: Herbicide Requirement and Price under Traditional and Zero Tillage Systems for an Average Farm in 1989

Herbicide	Price ($/L)	Herbicide Required (L/AC) (TT)	Herbicide Required (L/AC) (ZT)	($)/Acre (TT)	($)/Acre (ZT)
Avadex BW	8.80	1.50	1.50	13.20	13.20
Pardner (Bromoxynil)	10.96	0.41	0.41	4.49	4.49
Roundup (Glyphosate)	19.93	0.00	0.50	0.00	9.96
MCPA	3.75	0.00	0.34	0.00	1.28
2, 4–D	4.87	0.00	0.34	0.00	1.65
Total	––	**1.91**	**3.09**	**17.69**	**30.58**

Using the differences in crop production systems described above, the exogenous variables, $E(B_2), E(A_4), E(A_5)$, $E(A_6)$, and $E(B_6)$ can be calculated. The 31% decrease in the quantity needed of farm-owned labour and the 39% decrease in the quantity required of fuel imply an increase in the efficiency of these inputs and, thus, an increase in their corresponding parameters of input–augmenting technical change by the same percentage (i.e., $E(A_4) = 31\%$ and $E(A_5) = 39\%$). The 48% increase in the quantity needed of herbicide is mathematically equivalent to a decrease in the efficiency of an this input, and is modelled by assigning a negative sign to its corresponding parameter of input-augmenting technical change by the same percentage (i.e., $E(A_6) = -48\%$). The 6.6% increase in the cost of herbicide is treated by shifting upward the supply curve of herbicide by the same percentage (i.e., $E(B_6) = 0.066$). The 11% decrease in the cost of machinery service is treated by shifting downward the supply curve of this input by the same percentage (i.e., $E(B_2) = -0.11$). A summary of the exogenous variables values is presented in Table 4.11.

Table 4.11: Summary of the Exogenous Variable Values

Input		Exogenous Variables: Percentage Change in:	
		Input Efficiency $E(A_i)$	Input Price $E(B_i)$
Land	(X_1)	0.000	0.000
Machinery Service	(X_2)	0.000	-0.110
Other Variable Inputs	(X_3)	0.000	0.000
Farm-Owned Labour	(X_4)	0.310	0.000
Fuel	(X_5)	0.390	0.000
Herbicide	(X_6)	-0.480	0.066

4.6 The Impact of the Switch from TT to ZT Technology on Agricultural Input Suppliers in the Spring Wheat Industry in 1989 – The base-run Analysis:

Using the equilibrium displacement model presented in chapter 3, the impact of the switch from TT to ZT technology on agricultural input suppliers in the spring wheat industry in 1989 is examined. Specifically, the model estimates changes in prices and quantities at the output and inputs levels as a result of the technological change. Using the estimated prices and quantities, the welfare implications of the switch from TT to ZT technology to agricultural input suppliers are calculated.

4.6.1 The Estimated Changes in Prices and Quantities as a Result of the Switch from TT to ZT Technology

Equations (15) to (28) in chapter 3 are solved for the endogenous variables – the percentage changes in quantities and prices – by using the matrix algebra approach.

The first step in the solution is to transform the model so that the technology exogenous variables are on the right hand side of the equations and to write the model in matrix form as $MZ = G$ (M, Z and G are as defined in Chapter 3). The second step in the solution is to substitute the value of the parameters in Tables 4.6 and of the exogenous variables in Table 4.11 into M and G and simultaneously solve for the vector of the endogenous prices and quantities, $Z = M^{-1}G$, using any computer software with the ability to invert matrices. The estimated changes in quantities and prices are presented in Table 4.12.

4.6.2 The Change in the Welfare of Agricultural Input Suppliers in the Spring Wheat Industry as a Result of the Switch from TT to ZT Technology

In 1989, the total area sown to spring wheat on the Prairies was about 24.7M acres (10 Mha) (Campbell et. al, 2001). In the same year, spring wheat price was \$155/t and average yield was 0.73 t/acre (27 bushel/acre) (The Canadian Wheat Board, 2008; Saskatchewan Agriculture and Food, Economics Branch, Farm Management, 1989). Thus, the value of production, YP, is estimated to be \$2,795M. In addition, under the assumption of constant return to scale, the input i's share is calculated by $K_i = \frac{P_i X_i}{PY} = \frac{X_i}{Y} f_i$. Using the input i's cost share value, K_i from Table 4.6 and the value of production, YP, the input i's value, $X_i P_i$, can then be calculated. Substituting the value of inputs, $X_i P_i$, and the estimated changes in quantities and prices from Table 4.12 into equations (30)–(36) from chapter 3, the change in the welfare of agricultural input suppliers is calculated and presented in Table 4.13.

Table 4.13 shows that the aggregate impacts of the switch from TT to ZT technology on agricultural input sectors are as follows: (1) no change in the return to farm-owned labour sector; (2) a decrease in the total return to the fuel sector by \$16M; and (3) an increase in the return to land, machinery, other variable inputs and herbicide sectors by \$62M, \$18M, \$5M and \$30M, respectively. The total change in the return to the spring wheat industry is positive and equal to approximately \$100M. The quantitative results considering individual exogenous variables are discussed below.

Farm–Owned Labour Efficiency: Table 4.13 (column 2) shows that the 31% increase in the efficiency of farm–owned labour, $E(A_4)$, keeps the return to this sector unchanged and increases the return to land, machinery, other variable inputs, fuel and herbicide sectors by \$35M. The increase in the efficiency of labour (labour-saving technical change) leads to a downward shift in the demand curve of this input, an upward shift in the demand curve of the other inputs (land, machinery, other variable inputs, fuel, and herbicide) and an upward shift in the supply of output (Figure 4.1). The increase in the output results in an upward shift in the demand curves of all inputs as long as the output demand is elastic ($\eta > 1$).[8] Labour-saving technical change results in substituting the other inputs for the labour input as long as the elasticity of substitution is strictly positive ($\sigma_{ij} > 0$). The aggregate impacts of the shifts in output supply and input demand curves on output and inputs quantities and prices are as follows: (1) an increase in the quantity of output; (2) an increase in

[8] In the case of a single–output, two–input system, Muth (1964) shows that, as long as $\eta > 1$, an upward shift in the output supply curve increases the quantity of inputs i and j by: $-[(\sigma_{ij} + e_j)(1-\eta)\delta]/D$ and $-[(\sigma_{ij} + e_i)(1-\eta)\delta]/D$, respectively, and the price of inputs i and j by $-[(\sigma_{ij} + e_j)(1-\eta)e_i\delta]/D$ and $-[(\sigma_{ij} + e_i)(1-\eta)e_j\delta]/D$, respectively; where δ is an exogenous shift in the output supply and $D = \sigma(\eta + K_i e_i + K_j e_j) + \eta(K_j e_i + K_i e_j) + e_i e_j$ is positive.

the quantity and price of land, machinery, other variable inputs, fuel and herbicide; and (3) a decrease in the quantity of farm-owned labour (Table 4.12). Note that under the assumption of fixed price of farm-owned labour (farmers are engaged in off-farm work), the change in the price of this input is equal to zero, $E(P_4) = 0$, and thus, the return to labour sector is equal to zero, $\Delta PS_4 = 0$ (Tables 4.12 and 4.13).

Fuel Efficiency: Table 4.13 (column 3) shows that the 39% increase in the efficiency of fuel, $E(A_5)$, decreases the return to fuel sector by \$16M and increases the return to land, machinery, other variable inputs, and herbicide sectors by \$74M. The increase in the efficiency of fuel leads to a downward shift in the demand curve of this input, an upward shift in the demand curve of land, machinery, other variable inputs, farm-owned labour, and herbicide inputs and an increase in the supply of output.[9] Following the same interpretation of the increase in farm-owned labour efficiency, the aggregate effects of the shifts in output supply and input demand curves on output and input quantities and prices are as follows: (1) an increase in the quantity of output; (2) an increase in the quantity and price of land, machinery, other variable inputs, and herbicide; (3) an increase in the quantity of farm-owned labour; and (4) a decrease in the quantity and price of fuel (Table 4.12).

Herbicide Efficiency: Table 4.13 (column 4) shows that the 48% increase in the quantity needed of herbicide (i.e., $E(A_6) = -48\%$), increases the return to herbicide sector by around \$26M and decreases the return to land, machinery, other variable inputs, and fuel sectors by around \$102M. The decrease in the efficiency of herbicide

[9]Note that the downward shift in the demand curve of fuel and the upward shift in the demand curve of machinery won't change the demand of these inputs as the elasticity between these input is equal to zero ($\sigma_{25} = 0$).

leads to an upward shift in the demand curve of this input, a downward shift in the demand curve of other inputs (land, machinery, other variable inputs, farm-owned labour, and fuel) and a decrease in the supply of the output. The latter leads to a downward shift in the demand of all inputs as long as $\eta > 1$. The upward shift in the demand curve of herbicide (herbicide-using technical change) leads to a substitution of the herbicide input for the other inputs as long as $\sigma_{ij} > 0$. The aggregate impacts of the change in the efficiency of herbicides on the quantity and price of output and factors of production are as follows: (1) a decrease in the output quantity; (2) a decrease in the quantity and price of land, machinery, other variable inputs and fuel; (3) a decrease in the quantity of farm-owned labour; and (4) an increase in the quantity and price of herbicide (Table 4.12).

Machinery Service Cost: Table 4.13 (column 5) shows that the 11% decrease in the price of machinery service, $E(B_2)$, increases the return to land, machinery service, other variable inputs, fuel, and herbicide suppliers by \$93M. The decrease in the cost of machinery service results in a downward shift in the supply curve of this input, which leads not only to an increase in the quantity demanded of machinery service, but also to an increase in the quantity demanded of other inputs (land, other variable inputs, farm-owned labour, fuel and herbicide) as long as the elasticity of substitution between machinery and the other inputs is less than the absolute value of the output demand elasticity (i.e., $\sigma_{21}, \sigma_{23}, \sigma_{24}, \sigma_{25}$, and $\sigma_{26} < \eta$) (Table 4.12). This means that the factors of production are gross complements (i.e., the cross price elasticity of input demand, η_{ij}, is negative and that a decrease in the price of one input increases the demand of all inputs in production).[10]

Herbicide Cost: Table 4.13 (column 6) shows that the 6.6% increase in the cost of herbicide, $E(B_6)$, decreases the return to all input suppliers by \$11M. This is because when $\sigma_{ij} < \eta$, the factors of production are gross complements, and an increase in the price of herbicide decreases not only the quantity demanded of this input, but also the quantity demanded of other inputs (land, machinery service, other variable inputs, farm-owned labour, and fuel) in production (Table 4.12).

4.7 Sensitivity Analysis

In this section, a sensitivity analysis is performed on the specified point value of the parameters in Table 4.6 – the input cost shares (K_i), the input elasticities of substitution (σ_{ij}), and the input supply elasticities (e_i) – to test for the robustness of the base-run analysis results of the change in the return to input suppliers – the change in the total return to land, machinery, fuel, and herbicide and the change in the total return to the spring wheat industry.

A random sample of size 300 is generated from the base-run values of the total return to suppliers in table 4.13 (last column) by assigning three possible values for the parameters with equal probability of 1/3 – the initial base-run value, a value of -10%, and a value of +10%. Then random combinations of all the parameters

[10] Allen (1938; pp: 372-373) shows that the cross price elasticity of input demand, η_{ij}, is equal to: $\frac{E(X_j)}{E(P_i)} = K_j(\sigma_{ij} - \eta)$, $i \neq j$. When $\sigma_{ij} < \eta$, the cross price elasticity of input demand, η_{ij} is negative and the factors of production are gross complements, and when $\sigma_{ij} > \eta$, the cross price elasticity of input demand, η_{ij}, is positive and the factors of production are gross substitutes.

Base-Run Analysis

Table 4.12: The Estimated Changes in Prices and Quantities in the Spring Wheat Industry as a Result of the Switch from TT to ZT Technology in 1989

Output & Production Factors		The Change in the Efficiency of:			The Change in the Price of:	
		Labour	Fuel	Herbicide	Machinery	Herbicide
		$E(A_4)$	$E(A_5)$	$E(A_6)$	$E(B_2)$	$E(B_6)$
		=0.31	=0.39	=-0.48	=-0.11	=0.066
The Estimated Change in Quantities/Acre						
Output	$E(Y)$	0.00638	0.02589	-0.03824	0.03130	-0.00376
Land	$E(X_1)$	0.00286	0.00445	-0.00657	0.00538	-0.00065
Machinery Service	$E(X_2)$	0.00434	0.04663	-0.05207	0.05640	-0.00511
Other Variable Inputs	$E(X_3)$	0.00434	0.03525	-0.05207	0.04262	-0.00511
Farm-Owned Labour	$E(X_4)$	-0.23988	0.00956	-0.01412	0.01155	-0.00139
Fuel	$E(X_5)$	0.00434	-0.34322	-0.05207	0.05636	-0.00511
Herbicide	$E(X_6)$	0.00434	0.03525	0.32975	0.04262	-0.01476
The Estimated Change in Prices/Acre						
Land	$E(P_1)$	0.02857	0.04452	-0.06575	0.05381	-0.00646
Machinery Service	$E(P_2)$	0.00174	0.01865	-0.02083	-0.08744	-0.00205
Other Variable Inputs	$E(P_3)$	0.00174	0.01410	-0.02083	0.01705	-0.00205
Farm-Owned Labour	$E(P_4)$	0.00000	0.00000	0.00000	0.00000	0.00000
Fuel	$E(P_5)$	0.00174	-0.13729	-0.02083	0.02255	-0.00205
Herbicide	$E(P_6)$	0.00174	0.01410	0.13190	0.01705	0.06010

Base-Run Analysis

Table 4.13: The Change in the Welfare Economic of Agricultural Input Suppliers in the Spring Wheat Industry as a Result of the Switch from TT to ZT Technology in 1989

Sector		Returns to Factors of Production (Million $) as a Result of: The Change in the Efficiency of:			The Change in the Cost of:		Total Return (Millions $)
		Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.066	
Land	ΔPS_1	31.98	49.88	-73.26	60.32	-7.22	61.70
Machinery Service	ΔPS_2	1.46	16.00	-17.01	19.45	-1.71	18.19
Other Variable Inputs	ΔPS_3	0.73	6.02	-8.50	7.30	-0.86	4.68
Farm-Owned Labour	ΔPS_4	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	ΔPS_5	0.24	-15.89	-2.83	3.24	-0.29	-15.53
Herbicide	ΔPS_6	0.29	2.41	25.76	2.92	-0.98	30.40
Total		34.71	58.41	-75.84	93.22	-11.05	99.45

are chosen and for each combination the analysis is conducted and the outcome is recorded. The data descriptive statistics are presented in Table 4.14.

Table 4.14: Descriptive Statistics: The Change in the Return to Inputs Suppliers as a Result of the Change in the Parameters Values within a Range of ±10%

Change in the return to:	Obs	Mean	Std. Dev.	Min	Max
Land	300	60.34	8.94	37.06	82.99
Machinery	300	17.73	3.30	11.39	28.30
Other V. Inputs	300	4.42	1.16	1.68	7.734
Fuel	300	-15.68	1.69	-19.55	-12.31
Herbicide	300	30.64	3.08	24.34	38.01
Spring Wheat industry	300	97.45	11.65	71.28	127.96

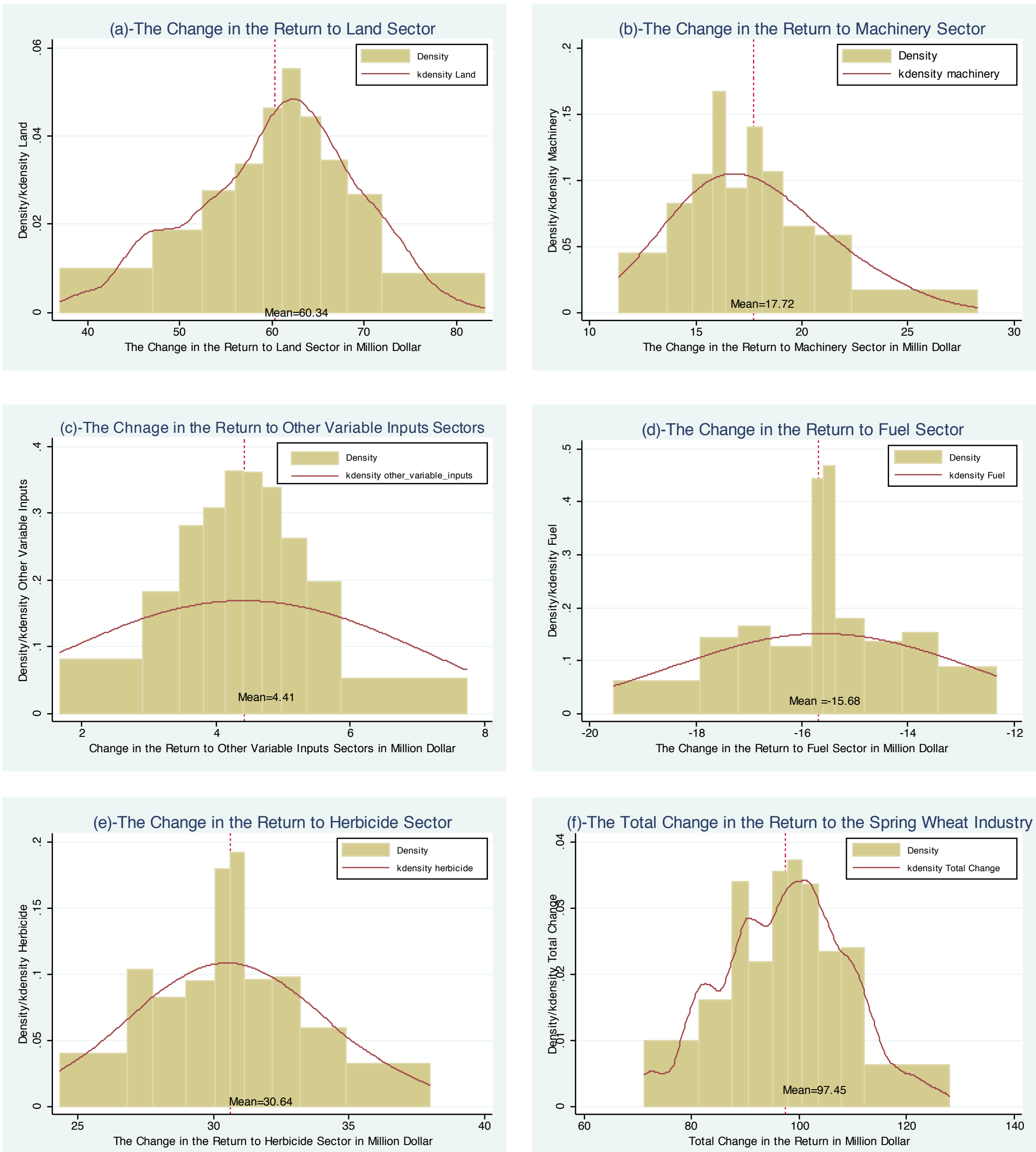
The random samples are graphically represented in Figure 4.4 $(a - f)$ to give an impression of the shape of the data distribution. In Figure 4.4 $(a - f)$, histograms bin boundaries are deciles, so that the area of each bin represents 10% of the total probability in the distribution. A kernel-density estimate and a mean sample are superimposed on the histograms in Figure 4.4 $(a - f)$. Kernel-density estimator is a natural development of a histogram which averages a kernel function across observations to construct a smooth probability density function of a random variable. In Figure 4.4, the y-value is an estimate of the probability density at the value of the change in the return to input suppliers (the x-value).

In Figure 4.4 (a), the kernel-density estimate indicates that land data follow, to a large degree, a normal distribution. Changing the base-run parameter values within a range of $\pm 10\%$ changes the return to land sector within a range of \$37M and \$83M with a mean equal to \$60.34M. The data around the mean in the interval [\$48M, \$72M] represents 80% of the sample size. In Figure 4.4 (b), the distribution of machinery data is skewed to the right but the kernel-density estimate which accounts for the skewness shows that the data are normally distributed. The change in the parameter values within a range of $\pm 10\%$ changes the return to machinery sector within a range of \$11M and \$28M with a mean equal to \$17.73M. The data around the mean in the interval [\$14M, \$22.5M] represents 80% of the sample size (Figure 4.4 (b)). The change in the return to the other variable inputs, fuel, and herbicide sectors in figure 4.4 (c) - (e) are interpreted similarly.

Figure 4.4 (f) shows that the change in the base-run parameter values within a range of $\pm 10\%$ changes the total return to the spring wheat industry within a range of \$71M and \$127M with a mean equal to \$97M. The kernel density estimate indicates that the total return to spring wheat industry data follow a normal distribution and more than 80% of the scores are between \$80M and \$120M.

The overall result of the sensitivity analysis suggested that the returns to agricultural input suppliers are reasonably robust to variations in the parameter values.

Figure 4.4: The Change in the Return to the Input Suppliers in the Spring Wheat Industry as a Result of the Change in the Parameter Values: A Sensitivity Analysis



4.8 Scenarios

In this section, the results of the base-run analysis are examined through the following five scenarios. Scenario (1) accounts for the potential differences in the effectiveness of the equipment technology under ZT and TT in 1989. Scenario (2) examines the impact of the change in the cost of herbicide. Scenario (3) examines the impact of the change in the price of output. Scenario (4) relaxes the assumption of farmers engaging in off-farm work. Finally, scenario (5) examines the long-run impact of the switch from ZT to TT technology. Table 4.21 summarizes the results of the base-run analysis and the results of the five scenarios.

Scenario (1): The Potential Differences in the Effectiveness of Equipment Technology under ZT and TT in 1989: A 10% Increase in the Percentage Change of the Machinery Service Cost

The base-run analysis does not account for the potential differences in the effectiveness of equipment technology under zero tillage and conventional tillage in 1989. For example, the model assumes that the drill no-till seeder under zero tillage performs as well as the drill disc press seeder under conventional tillage in 1989. If the performance of the ZT equipment is inferior to the performance of the TT equipment in 1989, the adoption of ZT technology generates an additional cost that farmers need to incur when using the ZT technology.

Assuming that the performance of the ZT equipment is inferior to the TT equipment performance in 1989, this scenario examines the impact of the switch from TT to ZT technology when all variables are at the base-run values except that the percentage change in the machinery cost saving, $E(B_2)$, falls by 10% to reflect the additional cost that farmers will incur because of the inferior machinery performance when adopting ZT technology. Table 4.15 presents the change in the welfare of input suppliers when all the variables are at the base-run values except that $E(B_2)$ is equal to -0.10.

Compared to the base-run analysis results, a 10% increase in the cost of machinery service reduces the total return to the spring wheat industry by 9%, decreases the return to land, machinery, and other variable inputs sectors by 9%, 10.5% and 15%, respectively; and negligibly changes the return to fuel and herbicide sectors (see Table 4.21 columns 1 and 2).

This result shows the importance of the effectiveness of ZT equipment in the adoption of ZT technology. For instance, the return to the land sector will be equal to zero and land-owners will have no incentive in adopting ZT, when the cost differential between ZT and TT equipment is equal to +0.011 (i.e., $E(B_2) = +0.011$).

Scenario (2): The Change in the Cost of Herbicide: A 10% Increase in the Percentage Change of the Herbicide Cost

Previous studies on the Prairies (e.g., Malhi et al. 1988, Smith et al. 1996, and Zentner et al. 1991 and 1992) have indicated that the high cost of herbicide (e.g., glyphosate) was regarded as a deterrent to the adoption of ZT technology in the 1980s. This scenario examines the change in the base-run results when the percentage change in the cost of herbicide increases by 10% (i.e., $E(B_6) = 0.076$). Table 4.16 presents the change in the return to input suppliers when all the variables are at the base-run analysis values except that $E(B_6)$ is equal to 0.076.

Compared to the base-run analysis, a 10% increase in the percentage change of herbicide cost decreases the return to the spring wheat industry by 1.7%, decreases the return to land, machinery, other variable inputs, and herbicide by 1.8%, 1.4%, 2.6%, 0.5%, respectively; and negligibly decreases the return to fuel sector (see Table 4.21 columns 1 and 3).

Scenario (3): The Change in the Price of Output: A 10% Increase in the Output Price

It is generally held that the increase in the price of output increases the farmers' adoption of agricultural technologies. Output price increases farmers' purchase power and encourages them to invest in new technologies. This scenario examines the change in the base-run results when the output price, P, increases by 10%. Table 4.17 presents the change in the return to input suppliers when all the variables are at the base-run analysis except that the output price, P, increases by 10% (i.e., $P = \$170.50$).

Compared to the base-run analysis, a 10% increase in the price of output increases the total return to the spring wheat industry by 10%, increases the return to land, machinery, other variable inputs, and herbicides each by 10%, and decreases the return to fuel sector by 10% (see Table 4.21 columns 1 and 4)

Scenario (4): Relaxing the Assumption of Farmers Engaging in Off-farm Work

In this scenario, the assumption of farmers engaging in off–farm work is relaxed and the supply elasticity of farm-owned labour, e_4, is given a value equal to 0.4. In this case, the price of farm-owned labour, P_4, is determined endogenously. Using the equilibrium displacement model in chapter 3, the change in the welfare of input suppliers as the result of the switch from TT to ZT technology is estimated and presented in Table 4.18, when all parameters are at the base-run values except that e_4 is equal to 0.4.

Table 4.18 shows that when $e_4 = 0.4$ the return to farm-owned labour decreases with the increase in the efficiency of farm-owned labour, the decrease in the efficiency and the increase in the price of herbicide; and increases with the increase in the efficiency of fuel and the decrease in the price of machinery service. The total return to farm-owned labour decreases by \$38.5M (Table 4.18 last column). The total return to land, machinery, other variable inputs and herbicides increases by \$100M, \$20M, \$5.5M, and \$31M, respectively; and the total return to fuel sector decreases by \$15M. Total return to the spring wheat industry is positive and equal to \$103M with most of the increase accruing to land sector (Table 4.18 last column).

Compared to the base-run analysis, relaxing the assumption of farmers engaged in off-farm work increases the return to land, machinery, other variable inputs, and herbicide sectors by 49%, 9%, 17%, and 1.2%, respectively; and decreases the return to fuel sector by around 2%. Total return to the spring wheat industry increases by 3.4% (see Table 4.21 columns 1 and 5).

Scenario (5): The Long-Run Impact of the Switch from TT to ZT Technology on Agricultural Input Suppliers in the Spring Wheat Industry

Agriculture and Agri–Food Canada (AAFC) (2010) examined the impact of the switch from the TT to ZT technology on soil quality on the Canadian Prairies during the period from 1981 to 2006 and concluded that the increased use of zero tillage contributed to the reduction of all forms of land degradation (i.e., soil organic matter depletion, soil erosion, and soil salinity) on the Prairies.

If the long-run increase in soil quality results in a decrease in the quantity of land required to produce the same amount of output, the index of factor-augmenting technical change of land, A_1, increases. In addition, in the long run, the supply elasticity of purchased inputs (machinery service, other variable inputs, fuel and herbicide) are normally more elastic. Using the equilibrium displacement model in chapter 3, this scenario examines the impact of the switch from TT to ZT technology on agricultural input suppliers when all parameters are at the base-run values except that the value of the percentage change in land efficiency, $E(A_1)$, increases by 1% and the value of purchased inputs supply elasticities are very elastic (i.e., $e_2 = e_3 = e_5 = e_6 = 20$).

Equations (16)–(22) show that the 1% increase in land efficiency leads to a downward shift in the demand curve of land, an upward shift in the demand curves of machinery, other variable inputs, fuel, and herbicide, and an upward shift in the supply curve of output. The aggregate effects of these shifts are an increase in the quantity of output and all factors of production (Table 4.19 column 1). Note that the increase in the efficiency of land does not decrease the quantity demanded of this input. This is because the increase in land quantity as a result of the upward shift in output supply curve outweighs the decrease in the quantity demanded of land as a result of the upward shift in the demand curve of other inputs and the downward shift in the demand curve of land.

Table 4.20 (column 1) shows that the 1% increase in the efficiency of land increases the return to land sector by \$10M and the return to machinery service, other variable inputs, fuel, and herbicide sectors by \$1M. Table 4.20 (last column) shows that, in the long run, when the supply elasticities of purchased inputs and land efficiency increase, the switch from the TT to ZT technology increases the return to land, machinery, other variable inputs, and herbicide sectors by \$96M, \$4M, \$1M, and \$4M, respectively; and decreases the return to fuel sectors by around \$2M. Total return to the industry in the long run is positive and equal to approximately \$103M.

Compared to the base-run analysis, the long-run impact of the switch from ZT to TT technology increases the return to land sector by 44%. Since the value of purchased inputs supply elasticities are very elastic, the return to machinery, other variable inputs, fuel, and herbicide sectors are expected to be close to zero in the long run. Total return to the spring wheat industry increases by 3.6% (see Table 4.21 columns 1 and 6).

4.9 Summary and Conclusion

This study uses an equilibrium displacement model to examine the welfare implications of the switch from TT to ZT technology on agricultural input suppliers in 1989.

The methodology applied in this study is unique in two respects. First, it treats the technological change by either modifying the production function using the specification of factor-augmenting technical change approach to reflect the change in the efficiency of inputs, or by shifting the input supply curves to reflect the change in the cost of production factors. Second, it allows for the changes in the efficiency and cost of the affected inputs to influence all production factors via the input supply and demand elasticities and the elasticity of substitution between inputs, thereby providing insight into how these changes impact the return to all input suppliers.

A representative farm of average size and soil moisture growing spring wheat is built to estimate the changes in the efficiency and cost of production factors as a result of the switch from TT to ZT technology. The results of this estimation show that the move to ZT decreases the need of farm-owned labour by 31% and of fuel by 39%, increases the need of herbicide by 48%, increases the cost per unit of herbicide by 6.6%, and decreases the cost per unit of machinery service by 11%.

The equilibrium displacement model parameter values – input cost shares (K_i), elasticity of demand for wheat (η), elasticities of substitution (σ_{ij}) and input supply elasticities (e_i) – are chosen from estimations of previous studies of the Canadian wheat industry and Canadian agriculture.

Results of the base-run analysis indicate that the increase in the efficiency of farm–owned labour and fuel increase the return to the industry by \$35M and \$58M, respectively; the decrease in the efficiency and the increase in the price of herbicide decrease the return to the industry by \$76M and \$11M respectively; and the decrease in the cost of machinery service increases the industry return by \$93M. Total return to land, machinery service, other variable inputs, and herbicide sectors increases by \$62M, \$18M, \$5M, and \$30M, respectively, and to fuel sector decreases by \$16M. Total return to the spring wheat industry is positive and equal approximately to \$100M. The base-run results show no change in the return to farm-owned labour sector when moving to ZT technology. This is due to the assumption that farmers engage in off-farm work and that they are paid at a fixed price equal to the off-farm work rate.

A sensitivity analysis is performed on the specified point value of the parameters. The analysis suggested that the returns to agricultural input suppliers are reasonably robust to variations in the parameter values.

The most important result in the base-run analysis is that land sector obtains most of the increase in the returns to the industry. The increase in the return to land is mainly due to the low supply elasticity of land. The increase in the return to land sector provides an incentive to land owners to adopt ZT technology.

The increase in the return to land sector from a technological change results in an increase in land price. Land return increases because technological advance lowers the cost of production, thus providing an incentive for land owners to expand their farm size, which in turn increases the demand for land and results in an increase in land price. The results of the base-run analysis show that, when moving to ZT technology, the return to land sector increases by $62M and thus the return per acre to land owners increases by $2.5 (in 1989, total land sown to spring wheat is 24.7M acres). At an interest rate equal to 5%, the present value of the perpetuity increase in the return to land is then equal to $50/acre. This value is expected to be absorbed by an increase in the price of land. Land operators do not capture any rent from the adoption of the ZT technology.

Since the equilibrium displacement model captures the aggregate behaviour at the industry level, it is important to recognize that when the change in the return to land sector is used to make inferences about the incentive of farmers to adopt ZT, the assumption is being made that farmers – when making their adoption decisions – they are rationally expecting other farmers to make the same adoption decision. In other words, the model assumes that farmers have a strong form of rational expectations – they understand the underlying model and know that others do as well.

The base-run results do not account for the potential differences in the effectiveness of equipment technology under ZT and TT in 1989. Scenario (1) examines the change in the base-run results when the performance of ZT equipment technology is seen as inferior to that of TT. This case is treated by increasing the percentage change in the machinery cost by 10%. The results show that a 10% increase reduces the total return to the spring wheat industry by 9%, decreases the return to land, machinery, and other variable inputs sectors by 9%, 10.5% and 15%, respectively; and negligibly changes the return to fuel and herbicide sectors.

Scenario (2) shows that a 10% increase in the percentage change in the herbicide cost decreases the return to the spring wheat industry by 1.7%, decreases the return to land, machinery, other variable inputs, and herbicide by 1.8%, 1.4%, 2.6%, 0.5%, respectively; and negligibly decreases the return to fuel sector. Scenario (3) shows that a 10% increase in the price of output increases the total return to the spring wheat industry by 10%, increases the return to land, machinery, other variable inputs, and herbicides each by 10%, and decreases the return to the fuel sector by 10%.

Scenario (4) shows that, compared to the base-run results, when the assumption of farmers engaging in off-farm work is relaxed, the return to farm-owned labour decreases by $38.5M. The return to land, machinery, other variable inputs, and herbicide sectors increase by 49%, 9%, 17%, 1.2%, respectively; the return fuel sector decreases by around 2% and the total return to the spring wheat industry increases by 3.4%.

In the long run, scenario (5) shows that, compared to the base-run results, when land efficiency increases by 1% and when the supply elasticities of purchased inputs go to infinite, the return to land sector increases by 44%, the returns to machinery, other variable inputs, fuel, and herbicide sectors go to zero, and the total return to the spring wheat industry increases by 3.6%.

In sum, we found evidence that the switch from ZT to TT technology increases the return to land, machinery, other variable inputs, and herbicide sectors in 1989. This result doesn't hold, if ZT equipment technology is not as effective as the TT equipment technology. We also found that the increase in the return to land sector is sensitive to the change in the price of herbicide and of output (spring wheat).

The positive return to machinery sector explains the increased incentive of different actors to be involved in the development of ZT equipment in the 1990s. The results also show that a 10% increase/decrease in the cost of herbicide would decrease/increase the return to herbicide sector by 0.5%. This result explains the incentive of herbicide sector to decrease the cost of herbicide.

The development of zero tillage equipment technology, the increase in the price of grain, and the dramatic decrease in the price of glyphosate during the 1990s–2000s could explain the change in the trend of ZT adoption from slow adoption during the 1980s to high adoption during the 1990s.

The analysis above was predicated on a representative farm and hence on the assumption that farmers are homogeneous. This suggests that if ZT technology is profitable and farmers are rational, then all farmers will adopt the technology. However, it is possible that farmers are heterogeneous, which means that they may not perceive the ZT profitability similarly. The source of heterogeneity resides in farmers' characteristics including variation in farmers' socio-economic conditions and management skills, and in the environmental and geographical conditions under which they operate. This variation can mean that different farmers differentially perceive and/or experience the benefits and costs of adopting ZT.

In addition, ZT technology is notable for its complexity and irreversibility, which increases the effort and time required to learn about its performance and makes waiting to adopt the technology valuable. Waiting enables farmers to acquire more information on the performance of ZT from neighbours who have already used the technology (neighbourhood effect), which in turn increases farmers' stock of knowledge and, thus, positively influences the adoption of ZT. The effects of neighbourhood and farmer characteristics on the adoption of ZT are analyzed in Chapter 5.

Scenario (1):

Table 4.15: The Change in the Welfare Economic of Agricultural Input Suppliers in the Spring Wheat Industry: A 10% Increase in the Percentage Change of the Machinery Service Cost

Sector		Returns to Factors of Production (Million \$) as a Result of:					Total Return (Millions \$)
		The Change in the Efficiency of:			The Change in the Cost of:		
		Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.10	Herbicide $E(B_6)$ =0.066	
Land	ΔPS_1	31.98	49.88	-73.26	54.82	-7.22	56.21
Machinery Service	ΔPS_2	1.46	16.00	-17.01	17.64	-1.71	16.38
Other Variable Inputs	ΔPS_3	0.73	6.02	-8.50	6.62	-0.86	4.01
Farm-Owned Labour	ΔPS_4	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	ΔPS_5	0.24	-15.89	-2.83	2.94	-0.29	-15.83
Herbicide	ΔPS_6	0.29	2.41	25.76	2.65	-0.98	30.13
Total		34.71	58.41	-75.84	84.67	-11.05	90.89

Scenario (2):

Table 4.16: The Change in the Welfare Economic of Agricultural Input Suppliers in the Spring Wheat Industry: A 10% Increase in the Percentage Change of the Herbicide Cost

Sector		Returns to Factors of Production (Million $) as a Result of:					
		The Change in the Efficiency of:			The Change in the Cost of:		Total Return (Millions $)
		Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.076	
Land	ΔPS_1	31.98	49.88	-73.26	60.32	-8.31	60.61
Machinery Service	ΔPS_2	1.46	16.00	-17.01	19.45	-1.97	17.93
Other Variable Inputs	ΔPS_3	0.73	6.02	-8.50	7.30	-0.98	4.56
Farm-Owned Labour	ΔPS_4	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	ΔPS_5	0.24	-15.89	-2.83	3.24	-0.33	-15.57
Herbicide	ΔPS_6	0.29	2.41	25.76	2.92	-1.13	30.25
Total		34.71	58.41	-75.84	93.23	-12.72	97.78

Scenario (3):

Table 4.17: The Change in the Welfare Economic of Agricultural Input Suppliers in the Spring Wheat Industry: A 10% Increase in the Price of Output

Sector		Returns to Factors of Production (Million $) as a Result of:					Total Return (Millions $)
		The Change in the Efficiency of:			The Change in the Cost of:		
		Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.066	
Land	ΔPS_1	35.18	54.87	-80.59	66.35	-7.94	67.88
Machinery Service	ΔPS_2	1.60	17.60	-18.71	21.39	-1.88	20.01
Other Variable Inputs	ΔPS_3	0.80	6.62	-9.35	8.03	-0.94	5.15
Farm-Owned Labour	ΔPS_4	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	ΔPS_5	0.27	-17.48	-3.12	3.56	-0.31	-17.08
Herbicide	ΔPS_6	0.32	2.65	28.34	3.21	-1.08	33.44
Total		38.18	64.25	-83.43	102.55	-12.16	109.40

Scenario (4):

Table 4.18: The Change in the Welfare of Agricultural Input Suppliers in the Spring Wheat Industry: Relaxing the Assumption of the Infinite Supply Elasticity of Farm-owned Labour

Sector		Returns to Factors of Production (Million \$) as a Result of:					Total Return (Millions \$)
		The Change in the Efficiency of:			The Change in the Cost of:		
		Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.066	
Land	ΔPS_1	71.63	48.30	-70.96	58.41	-6.99	100.40
Machinery Service	ΔPS_2	3.27	15.93	-16.91	19.36	-1.70	19.95
Other Variable Inputs	ΔPS_3	1.64	5.98	-8.45	7.25	-0.85	5.56
Farm-Owned Labour	ΔPS_4	-39.54	1.71	-2.51	2.07	-0.25	-38.52
Fuel	ΔPS_5	0.55	-15.90	-2.82	3.22	-0.28	-15.23
Herbicide	ΔPS_6	0.65	2.39	25.79	2.90	-0.98	30.76
Total		38.19	58.41	-75.85	93.21	-11.05	102.92

Scenario (5): Long-Run Analysis

Table 4.19: The Estimated Changes in Prices and Quantities in the Spring Wheat Industry as a Result of the Switch from TT to ZT Technology in 1989: The Case of the Change in Land Efficiency and Purchased Input Supply Elasticity in the Long-Run

Output & Production Factors		The Change in the Efficiency of:				The Change in the Price of:	
		Land $E(A_1)$ =0.01	Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.066
The Estimated Change in Quantities/Acre							
Output	$E(Y)$	0.01058	0.00754	0.02791	-0.04123	0.04499	-0.00540
Land	$E(X_1)$	0.00093	0.00306	0.00480	-0.00709	0.00773	-0.00093
Machinery Service	$E(X_2)$	0.01031	0.00624	0.04904	-0.05915	0.07907	-0.00775
Other Variable Inputs	$E(X_3)$	0.01031	0.00624	0.04005	-0.05915	0.06455	-0.00775
Farm-Owned Labour	$E(X_4)$	0.01085	-0.23945	0.01030	-0.01522	0.01660	-0.00199
Fuel	$E(X_5)$	0.01031	0.00624	-0.34084	-0.05915	0.07904	-0.00775
Herbicide	$E(X_6)$	0.01031	0.00624	0.04005	0.34324	0.06455	-0.01791
The Estimated Change in Prices/Acre							
Land	$E(P_1)$	0.00928	0.03056	0.04799	-0.07088	0.07735	-0.00928
Machinery Service	$E(P_2)$	0.00052	0.00031	0.00245	-0.00296	-0.10605	-0.00039
Other Variable Inputs	$E(P_3)$	0.00052	0.00031	0.00200	-0.00296	0.00323	-0.00039
Farm-Owned Labour	$E(P_4)$	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Fuel	$E(P_5)$	0.00052	0.00031	-0.01704	-0.00296	0.00395	-0.00039
Herbicide	$E(P_6)$	0.00052	0.00031	0.00200	0.01716	0.00323	0.06510

Scenario (5): Long-Run Analysis

Table 4.20: The Change in the Welfare Economic of Agricultural Input Suppliers in the Spring Wheat Industry as a Result of the Switch from TT to ZT Technology in 1989 – The Case of the Change in Land Efficiency and Purchased Input Supply Elasticity in the Long-Run

Sector		Returns to Factors of Production (Million $) as a Result of: the Change in the Efficiency of:				the Change in the Cost of:		Total Return (Millions $)
		Land $E(A_1)$ =0.01	Labour $E(A_4)$ =0.31	Fuel $E(A_5)$ =0.39	Herbicide $E(A_6)$ =-0.48	Machinery $E(B_2)$ =-0.11	Herbicide $E(B_6)$ =0.066	
Land	ΔPS_1	10.38	34.22	53.78	-78.95	86.80	-10.37	95.85
Machinery Service	ΔPS_2	0.43	0.26	2.11	-2.41	3.45	-0.32	3.52
Other Variable Inputs	ΔPS_3	0.22	0.13	0.86	-1.20	1.40	-0.16	1.24
Farm-Owned Labour	ΔPS_4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel	ΔPS_5	0.07	0.04	-1.98	-0.40	0.57	-0.05	-1.74
Herbicide	ΔPS_6	0.09	0.05	0.34	3.37	0.56	-0.15	4.26
Total		11.19	34.71	55.11	-79.59	92.78	-11.06	103.13

Table 4.21: Total Change in the Welfare of Agricultural Input Suppliers in the Spring Wheat Industry: Results Summary

Sector		Returns to Factors of Production (Million $)					
		Base-Run Analysis	Scenario (1): 10% Increase in the % Change of Mach. Cost	Scenario (2): 10% Increase in the % Change of Herb. Cost	Scenario (3): 10% Increase in the Price of Output	Scenario (4): Relaxing the Assump. of Off-Farm	Scenario (5): Long-Run Analysis
Land	ΔPS_1	61.7	56.21	60.61	67.88	100.4	95.85
Machinery Service	ΔPS_2	18.19	16.38	17.93	20.01	19.95	3.52
Other Variable Inputs	ΔPS_3	4.68	4.01	4.56	5.15	5.56	1.24
Farm-Owned Labour	ΔPS_4	0	0	0	0.00	-38.52	0
Fuel	ΔPS_5	-15.53	-15.83	-15.57	-17.08	-15.23	-1.74
Herbicide	ΔPS_6	30.4	30.13	30.25	33.44	30.76	4.26
Total		99.45	90.89	97.78	109.40	102.92	103.13

Chapter 5

The Effects of Neighbourhood and Farmer Characteristics on the Adoption of Zero Tillage: The Horizontal Market Analysis

5.1 Introduction

As indicated in previous chapters, zero tillage (ZT) is a revolutionary technology that requires practitioners to change their knowledge of the biophysical environment, new management practices, and an investment in a new type of equipment. Because of its complexity and the irreversibility, zero tillage requires farmers to invest some time to learn about its performance. As a result, information is important in mitigating the impacts of uncertainty and sunk costs and, thus, creates a value to waiting (real option value of waiting). In this study, waiting may enable potential adopters to acquire more information on the performance of ZT from neighbours who have already used the technology (neighbourhood effect), which in turn increases their stock of knowledge and, thus, positively influences adoption of this technology.

In geography, the neighbourhood effect asserts that the closer a potential adopter is to another individual who has already adopted the technology, the greater the probability of social interactions (involving communication, persuasion and imitation) and the greater the likelihood that he will adopt the new technology before potential adopters who are further away (Cohen, 1972; Hägerstrand, 1952, 1967; Rogers, 1962). This pattern is consistent with the findings of the spatial diffusion model of innovation, proposed by Hägerstrand (1952), which assumes that farmers share information and learn new practices from each other through social activities which may involve travel and transport costs, and these costs increase with distance.

An important component of the adoption decision–making process is the variation in farmers' characteristics. The adoption of an innovation is related to the acceptance or rejection of information, which in turn reflects a wide range of farmers' characteristics. Variations in these characteristics are determined by farmers' economic, socio–economic, and management skills, and by the environmental conditions under which farmers operate. For instance, Forster and Stem (1979), Baron (1981), Ervin (1981) and Norris and Batie (1987) studied the factors that influence the adoption of conservation tillage and found that more educated and younger farmers seek and use new information to a greater degree than the less educated and older farmers; this in turn tends to positively affect the adoption of this technology. They also found that factors such as farm size, tenure status, off–farm employment and soil erosion level affect soil conservation technology adoption.

This chapter analyzes how factors such as neighbourhood and farmers' characteristics (including personal and farm business characteristics) have influenced the adoption of ZT technology on the Canadian Prairies over time. To meet this objective, a model of heterogeneous farmers' decision-making, their adoption or non-adoption and resultant effects on patterns of land-management practice, is used under a waiting option framework. The theoretical predictions are then empirically tested using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for the three Prairie provinces – Alberta (AB), Saskatchewan (SK) and Manitoba (MB).

The chapter is structured as follows. Section two reviews the literature on the adoption and diffusion of innovations. Section three describes the heterogeneous farmer model of zero tillage adoption decision underpinning the empirical work. Section four presents the results of the empirical work, a description of the database, and an overview of the methodology. Finally, section five summarizes the main findings and concludes the chapter.

5.2 Adoption and Diffusion

Because of its importance as a determinant of economic growth, adoption of innovation attracted considerable attention among scientists from different disciplines. Rogers (1962) defined adoption of innovation as "the mental process an individual passes from first hearing about an innovation to final adoption" (p. 17). He indicated that an individual adoption decision progresses through five stages: knowledge (in which an individual is first exposed to an innovation), persuasion (in which an individual shows interest and seeks information about the innovation), decision (in which an individual decides whether to adopt or reject the innovation), implementation (in which an individual tries the innovation), and confirmation (in which an individual decides to continue or discontinue using the technology).

Rogers (1962, 1983, and 1995) indicated that if the technology is adopted, it diffuses through communication networks over time and space. He studied the diffusion of hybrid corn in different counties of the US and concluded that the spread of this technology over time follows a bell-shaped frequency distribution over time (S-shape curve). Breaking this normal distribution into segments, adopters are divided into five categories: innovators, early adopters, early majority, late majority, and laggards accounting for 2.5%, 13.5%, 34%, 34%, and 16% of the population, respectively. Griliches (1957, 1958), Mansfield (1963), Lehvall and Wahlbin (1973) used the S–shape diffusion curve by incorporating various economic factors.

The literature on technology diffusion is based on two theoretical approaches: the disequilibrium approach and the equilibrium approach. The disequilibrium approach, also known as the epidemic approach, emphasizes the role played by information dissemination in the diffusion process of an innovation. This approach assumes that diffusion is a disequilibrium process resulting from information symmetries between adopters and potential adopters of the technology in every period (Griliches, 1957; Rogers, 1962). The greater the number of previous adopters, the more information is released, and the greater is the adoption of the technology over time. Under this approach, the diffusion path follows a logistic curve (the S-shape diffusion curve) where there is an initial period (the period when the technology is introduced) a takeoff period, and a saturation period. During the initial and takeoff periods, the rate of diffusion increases until it reaches an inflection point and then decreases during the saturation period until it reaches a peak point (Sunding and Zilberman, 2001). The major weakness of the disequilibrium approach lies in its embedded assumptions of homogenous potential adopters and of the fixed profitability of the technology across adopters and over time (Stoneman, 1983).

The alternative to the disequilibrium approach – the equilibrium approach or the threshold approach – was introduced by Paul David (1969) to examine the adoption of grain harvesting equipment in the United States. This approach assumes that, at any period of time, potential adopters are heterogenous and operate under full information on the nature of the new technology, each potential adopter pursues maximizing or satisfying behaviour, and the adoption of the new technology requires a fixed cost (e.g., investment in new equipment and in learning) that varies over time. Heterogeneity of potential adopters results in differences in adoption timing. As time goes on, the fixed cost of adoption declines and the spread of the technology extends. The main limitation of the equilibrium approach lies in its assumption of the availability of full information on the nature of the new technology during the diffusion process.

For the purposes of theoretical and empirical analysis, Feder and Umali (1993) and Sunding and Zilberman (2001) distinguished between the adoption and diffusion of agricultural innovations by using two approaches. At the entity level, each entity decides whether to adopt or reject a technology and determines the intensity of technology utilization if adopted. Measures of adoption behaviour, therefore, can be captured by a discrete choice (i.e., whether an entity does or does not use an innovation at a certain time) or by a continuous variable (i.e., the intensity of use of an innovation which can be measured, for example, by the percentage of the entity's land planted with a certain technology). At the aggregate level, the adoption progress of all entities is examined over time to determine the trend in the diffusion cycle. Diffusion measures can be depicted by the percentage of population that adopted the technology or by the percentage of land covered by the new technology.

Adoption of innovations in agriculture is not uniform and static. Some innovations have been adopted by large groups of farmers while others have been adopted by only a small group of farmers (Feder et al., 1985). Adoption of an agricultural innovation involves a balancing act between different elements related to the innovation characteristics and farmer attributes. For instance, Feder et al. (1982, 1985), Feder and Just (1980) and Feder and O'Mara (1981) indicated that innovations that require greater investment in fixed costs are adopted at a higher rate by larger farmers, and innovations characterized by a higher level of complexity are adopted by farmers with higher access to information sources (e.g., contact with farmers who had already adopted the technology and with agricultural extension agents). Other farmer characteristics, such as credit availability, adequate human capital, and tenure status, and factors related to the conditions in which farmers operate such as access to input markets, physical environment of the farm and transportation infrastructure state are seen as determinants to the adoption of agricultural innovations.

The empirical studies on the adoption of conservation tillage practices have identified a number of commonly assessed factors that are correlated to farmer decision to adopt or not adopt such farming practices. Factors found by previous studies to affect farmers' adoption decision of conservation tillage are presented in Table 5.1.

In this chapter, the adoption of zero tillage is defined as the farmer's decision to adopt or not adopt the technology under the influence of information on this technology acquired from neighbours who have already adopted it and of a range of factors related to farmer personal characteristics such as age, education, and off-farm employment and farm business related characteristics such as tenure status, farm size, distance to research station and urban centre, and soil type and erosion level. In this study, information about the performance of ZT is not fully available during the adoption process. At the beginning of each period, heterogenous farmers decide to adopt or not adopt the ZT technology under the influence of the available information on this technology. At the end of each period, information about the performance of ZT is released by previous adopters and, through social interactions, this information is added to the stock of knowledge of the potential adopters and positively influences their adoption over time. Based on this definition, this study links the two theoretical approaches to technology diffusion by using the assumption of incomplete information on the technology associated with the disequilibrium approach, and by using the assumption of heterogenous potential adopters associated with the equilibrium approach.

Table 5.1: Factors Found by Previous Studies to Affect farmers' Adoption of Conservation Tillage

Study/Factor	Soil Quality Awareness	Educ.	Age	Income	Off-Farm Employ.	Info. Source	Gover. Subsidy	Farmers Networks	Org. Membership
Seitz and Swanson (1980)	✓								
Carlson and Dillman (1983)			✓						
Napier et al. (1984)			✓						
Rahm and Huffman (1984)		✓	✓			✓			
Gartrell &Gartrell (1985)				✓					
Shortle and Miranowski (1986)		✓							
Green and Heffernan (1987)	✓		✓						
Nowack (1987)	✓								
Gould et al.(1989)	✓	✓	✓	✓					
Smit and Smithers (1992)									✓
Warriner and Moul (1992)		✓	✓					✓	
Napier and Camboni (1993)	✓				✓		✓		
Saltiel et al. (1994)		✓		✓					
Westra and Olson (1997)		✓				✓			
Clay et al. (1998)		✓	✓						
Okoye (1998)		✓	✓						
Traore et al. (1998)	✓						✓		
Uri (1998)		✓							
Fuglie (1999)	✓				✓				
Neill and Lee (1999)			✓						
Soule et al. (2000)							✓		
Swinton (2000)					✓		✓		✓
Somda et al. (2002)				✓					
Davey and Furtan (2008)		✓	✓	✓	✓				

5.3 Theoretical Model

In this section, a model of heterogeneous farmers' decision–making is presented under a waiting option framework. Waiting option theory has been widely used in previous studies (e.g., Demont et al., 2004; Galushko et al., 2011; Myers, 1977; Scandizzo and Savastano, 2010; Wesseler et al., 2007; Wesseler, 2009) to model agents' adoption decisions to invest in technologies characterized by complexity and irreversibility. Irreversibility from adoption may originate in the sunk costs (e.g., learning of a new management practice and investment in new types of inputs) that an agent bears as a result of the switch from the traditional to the new technology.

Complex and irreversible technology requires more information and it takes more time to learn about its performance. As a result, information is important in mitigating the impacts of uncertainty and sunk costs and, thus, creates a value to waiting. In this respect, zero tillage adoption, which requires a change in the knowledge of the biophysical environment, learning of new management practices and investment in a new type of equipment, can be best explained in a waiting option framework.

More specifically, the model assumes that, in a given period, the decision to adopt zero tillage technology or to keep using the traditional one is derived from the maximization of the relative return function. Thus, the solution to the optimization problem is a discrete choice which determines the type of technology the farmer will use in each period. At the end of each period, information about the performance of zero tillage is realized from farmers that have already adopted it. Through social communication, this information is added to the stock of knowledge of potential adopters and used in their decision-making in the next period.

5.3.1 Model Assumptions

The model builds on previous work by Fulton and Giannakas (2004) and Galushko et al. (2011). In this model, farmers are assumed to differ in the relative returns they receive from growing a crop under ZT and TT technology. Source of differences reside in farmers' socio–economic conditions and management skills, and in environmental and geographical conditions under which they operate.

Following the previous work by Galushko et al. (2011) who studied decision-making by heterogeneous farmers in the adoption of new seed varieties under a waiting option framework, the model assumes that, at time t, the farmer who choses to adopt the technology incurs a cost V_t, where V_t represents the value of the option to wait and adopt the technology in the future. In other words, V_t is the loss that a farmer sustains by not waiting until the next period to adopt the technology and benefit from the released information about its performance from early adopters.

At time t, the net return function of the farmer is then given by

$$\Pi_t^Z = P - W^Z - \beta A - V_t \quad \text{if a unit of product is produced under zero tillage} \tag{1}$$

$$\Pi^T = P - W^T \quad \text{if a unit of product is produced under traditional tillage} \tag{2}$$

where Π_t^Z and Π^T are the profits associated with the production of a unit of product under ZT and TT, respectively. The parameter P is the per-unit price of the product. The terms W^Z and W^T are the costs (e.g., the cost of machinery service, seed, labour, herbicide, fuel, and fertilizer) of producing a unit under ZT and TT, respectively. It is assumed that $W^Z < W^T$, which indicates that producing a unit under

ZT is more cost–effective than under TT technology. Farmers are assumed to be uniformly distributed in the interval $[0, 1]$, each producing one unit of a product under their preferred technology, ZT or TT. The parameter A denotes the attribute that differentiates producers, for example land tenure, farm size, education, age, off-farm employment, access to information sources, soil type, and erosion level. Attribute A is uniformly distributed with unit density $f(A) = 1$ in the interval $A \in [0, 1]$. The greater is the differentiating farmer attribute, A, the lower is farmer preference for ZT technology. For instance, farmers with higher A values derive lower profit from producing a product under ZT compared to farmers with low A values. The parameter β is a non-negative, cost-enhancement factor that is constant across all farmers. In this context, βA represents the additional cost that a farmer with attribute A incurs when using ZT technology. For simplicity and without loss of generality, it is assumed that the cost-enhancement parameter of producing a unit of product under TT is equal to zero.

A farmer's adoption decision is determined by comparing the profit derived from producing a unit of product under ZT and TT so the farmer with a differentiating characteristic $\hat{A}_t = \frac{W^T - (W^Z + V_t)}{\beta}$ (found by equating $\Pi_t^Z = \Pi^T$) is indifferent between producing a product under ZT and TT technology. Farmers with $A \in [0, \hat{A}_t)$ find it optimal to produce under ZT, while farmers with $A \in [\hat{A}_t, 1]$ produce under TT (see Figure 5.1). Given that farmers are uniformly distributed in the interval $[0, 1]$, the indifferent farmer, $\hat{A}_t$, also determines the aggregate adoption (the share) of ZT and TT technology at time t, given by equations (3) and (4), respectively.

$$X_t^Z = \hat{A}_t = \frac{W^T - (W^Z + V_t)}{\beta} \tag{3}$$

$$X_t^T = 1 - \hat{A}_t = \frac{\beta - W^T + (W^Z + V_t)}{\beta} \tag{4}$$

Equation (3) shows that for the ZT technology to be adopted the sum of the production and waiting option costs, $W^Z + V_t$, under ZT should be less than the production cost, W_T under TT; otherwise the profit curve Π_t^Z will lie below the profit curve Π^T for all A values and all farmers will produce under TT technology.

At time $t+1$, information about the performance of zero tillage is realized from farmers who have already adopted the technology at time t. Through social communication, this information is added to the stock of knowledge of potential adopters. The greater the proportion of farmers who adopted ZT technology at time t, the more information is released, the greater is the stock of knowledge for potential adopters, and the lower is the uncertainty about the performance of ZT at time $t+1$. In this context, the option value of waiting at time $t+1$ is a decreasing function of the proportion of the ZT users at time t, X_t^Z. If farmers share their information, the option value of waiting at time $t+1$ is given by $V_{t+1} = V_t(1 - X_t^Z)$ (Galushko et al. 2011).

At time $t+1$, the net return function of the farmer with attribute A from using ZT technology is then given by:

$$\Pi_{t+1}^Z = P - W^Z - \beta A - V_t(1 - X_t^Z) \tag{5}$$

A time $t+1$, the farmer with a differentiating characteristic $\hat{A}_{t+1} = \frac{W^T - (W^Z + V_t(1 - X_t^Z))}{\beta}$

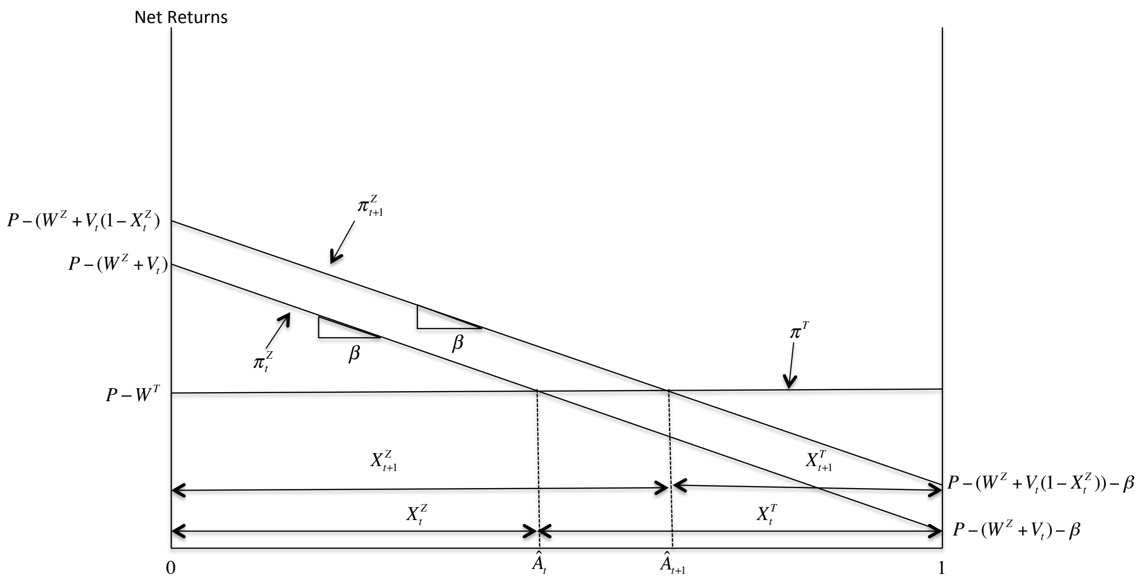
(found by equating $\Pi^Z_{t+1} = \Pi^T$) is indifferent between producing a product under ZT and TT technology. Farmers with $A \in [0, \hat{A}_{t+1})$ find it optimal to produce under ZT, while farmers with $A \in [\hat{A}_{t+1}, 1]$ produce under TT (see Figure 5.1). The indifferent farmer, $\hat{A}_{t+1}$, also determines the aggregate adoption (the share) of ZT and TT technology at time $t+1$, given by equations (6) and (7), respectively.

$$X^Z_{t+1} = \hat{A}_{t+1} = \frac{W^T - (W^Z + V_t(1 - X^Z_t))}{\beta} \quad (6)$$

$$X^T_{t+1} = 1 - \hat{A}_{t+1} = \frac{\beta - W^T + (W^Z + V_t(1 - X^Z_t))}{\beta} \quad (7)$$

Equation (6) shows that the greater the proportion of farmers who used the ZT technology at time t, X^Z_t, the lower the option value of waiting, $V_t(1 - X^Z_t)$, and the higher the proportion of farmers who use the ZT technology at time $t+1$, X^Z_{t+1}. This case is shown graphically in Figure 5.1 by shifting upward the return curve of ZT technology from Π^Z_t to Π^Z_{t+1} indicating an increase in the return to farmers from producing under ZT technology by $V_t(X^Z_t)$ and, thus, an increase in the proportion of farmers who adopted this technology by the interval $[\hat{A}_t, \hat{A}_{t+1}]$. Farmers with characteristics $[\hat{A}_t, \hat{A}_{t+1}]$, who were producing under TT technology at time t, find it optimal, at time $t+1$, to adopt ZT technology after benefiting, through social communications, from the released information by early adopters.

Figure 5.1: Farmers' Decisions to Adopt ZT or to Keep Using TT under Waiting Option Framework



The above results are based on the assumption that the cost of producing a product under ZT is less than under TT technology. If ZT were more costly than TT technology, the return curve for the ZT technology would lie below the return curve of TT technology for all farmers, resulting in no–adoption of ZT technology. In addition, the results are based on the assumption that farmers share their information on ZT. The relaxing of this assumption will result in an increase in the option value cost of waiting and in a lower adoption of ZT technology. Finally, relaxing the assumption that farmers are uniformly distributed in the unit length interval with respect to their differentiating characteristics and, for example, allowing the distribution to be skewed to the left so that more farmers have a strong preference for ZT technology, will increase the adoption of ZT technology.

5.4 The Empirical Model

The theoretical model presented above emphasizes the role of farmers' characteristics, economic factors (i.e., input costs), and social communications with previous adopters in shaping the adoption of ZT technology over time. This section aims at empirically testing the effect of these factors on the adoption of ZT technology by using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for the three Prairie provinces –Alberta, Saskatchewan and Manitoba.

CCSs represent a consolidation of two or more subdivisions, which are usually municipalities. Generally, an urban census subdivision (town, village, etc.) is incorporated with the surrounding municipality and they are consolidated to form an intermidiate geographic level between the census subdivision (CSD) and the census division (CD) (Statistics Canada, 2002).

In this study, social communications with previous adopters is captured by using the concept of neighbourhood effect. In geography, the neighbourhood effect – postulated by Hägerstrand (1952), who analyzed the spatial diffusion of agricultural innovations in Sweden – suggests that farmers who adopt the new technology tend to be the neighbours of previous adopters. Hägerstrnad (1952) assumes that farmers in different geographic locations share information and learn new practices from each other through social activities which may involve travel and transport costs, and these costs increase with distance. Given this assumption, it is possible to test the neighbourhood effect in area i at time t with the following index (Hedstrom et al., 2000; Hedstrom, 1994; Land and Deane, 1992; Rudel and Roper, 1997; Tolnay, 1995):

$$N_{it} = \sum \frac{n_{j(t-1)}}{d_{ij}} \tag{8}$$

where d_{ij}, used as a proxy for transportation costs, is the distance between areas i and j and the term $n_{j(t-1)}$ is the number of farms that adopted the new technology in area j at time $(t-1)$.

The farmer characteristic variables considered in this study are divided into two groups. The first group is related to farmers' personal characteristics, P, including age, education and off–farm employment variables. The second group is related to the farm business characteristics (i.e., the conditions in which farmers operate), B, including farm size, tenancy, distance to research stations and urban centre, and soil erosion and type conditions.

In this study, the economic factors are controlled implicitly by using time-dummy variables. Time dummies are generally used to control for unobserved time-varying effects such as government regulatory and/or tax policies at the national level, economic conditions, and technology change.

The equation for the adoption of ZT technology is given by

$$y_i = f(N, P, B) + u_i \tag{9}$$

where N, P and B are as defined before. The term y_i is the dependent variable and represents the choice of i^{th} farmer to adopt ZT technology. The term u_i is a well-behaved random disturbance term.

Since data at the farm–level are not available for us to estimate equation (9), data of ZT adoption at the CCS level for AB, SK and MB are used. Following Scandizzo and Savastano (2010), and denoting time with the subscript t, we can rewrite equation (9) as

$$Y_{it} = \sum_{i=1}^{n} y_{it} = g(N, P, B) + \sum_{i=1}^{n} u_{it} \qquad (10)$$

Because the percentage of land planted with ZT technology can be considered as a measure of adoption (see Feder and Umali, 1993; Sunding and Zilberman 2001), equation (9) can, therefore, be specified as

$$L_{it} = Y_{it}L_t = L_t \sum_{i=1}^{n} y_{it} = h(N, P, B) + \sum_{i=1}^{n} V_{it} \qquad (11)$$

where L_{it} denotes the percentage of acres under ZT technology in the i^{th} CCS in the t^{th} year, L_t is the cropland under ZT at time t, and V_{it} is a well–behaved random disturbance term.

This study uses the random-effects (RM) generalized least squares (GLS) model to examine the effect of the neighbourhood and farmer characteristic factors on the adoption of ZT technology (the percentage of land planted with ZT technology). The model coefficients are estimated by employing the STATA 2011 statistical software. The advantage of using a panel dataset over cross–sectional or time–series datasets is that a panel data gives a larger number of observations, increases the degrees of freedom, reduces collinearity among variables and, therefore, improves the econometric estimation efficiency. In addition, a panel dataset is better suited for dynamic studies because of its ability to control for variables that are not observed or measured like learning, and to control for differences across entities and over time. That is, panel models accounts for entity (i.e., CCS) heterogeneity (Gujarati 2003).

The RM model assumes that entity heterogeneity (the variation across CCSs) is random and uncorrelated with the independent variables. The RM model is given by:

$$L_{it} = \alpha + \beta_1 N_{it} + \beta_2 P_{it} + \beta_3 B_{it} + u_i + \varepsilon_{it} \tag{12}$$

where the term u_i is the between-CCSs error, the term ε_{it} is the within-CCSs error, the term α is a constant, and β_1, β_2 and β_3 are the independent variable coefficients. All other variables are as previously defined.

To test whether to use the RM model or the simple OLS model, the Breusch-Pagan Lagrange multiplier (LM) test is used (see Table 5.6). The null hypothesis in the LM test is that differences across CCSs is zero. The LM test shows that the P > chi2 = 0.00 (Table 5.6). Thus, we reject the null and conclude that there is evidence of significant differences across CCSs and that the use of the RM model is appropriate.

In this study, some of the explanatory variables (i.e, distances, soil type and soil erosion variables) are time-invariant. In this case, the RM model is preferable to fixed effects (FE) and first differences (FD) models because of its ability to investigate time-invariant causes of the dependent variable.

To test for the collinearity among continuous independent variables the variance inflation factor (VIF) test in Stata is used (see Table 5.7). A VIF value greater than

10 is generally seen as indicative of collinearity among the independent variables. Table 5.7 shows that the data has no collinearity problem. To test for panel data heteroskedasticity the likelihood ratio (LR) test is used (see Table 5.8). The null is homoskedasticity or constant variance. The LR test shows that the P > chi2 = 1.00 (Table 5.8). Thus, we fail to reject the null and conclude no heteroskedasticity problem in the data. In this study, the serial correlation is not a problem since the data is micro panels (few years and very large observations) (Greene 2008). However, to control for any potential serial correlation in the data, this study uses the option robust standard errors in Stata.

One potential problem when using geographical data is that the residuals could be spatially autocorrelated. The presence of the spatial autocorrelation affects the estimation of the standard errors. Thus, to correct for this problem the model is estimated by using the clustering approach. The cluster approach assumes that the residuals are correlated within particular geographic clusters but uncorrelated across clusters. The clusters used in this study are the census division (CD) areas. The CDs are intermediate geographic areas between the provinces and the census subdivisions levels (Statistics Canada 2002).

One way to examine the effect of the neighbourhood and farmer characteristic factors on the adoption of ZT technology is to use the Tobit model. The Tobit model has been applied in studies of adoption of agricultural innovations (e.g., Adesina and Zinnah, 1993; Cornejo et al., 2001; Gould et al., 1989; Maddalla, 1992; Norris and Batie, 1987; Rosett and Nelson, 1975) to estimate the likelihood of adoption and the intensity of adoption when the dependent variable is truncated and continuous between a certain lower and upper limit. In this study, the dependent variable, which is the proportion of acreage planted using the ZT technology, has a censored distribution between zero and one (zero for those not adopting the technology). However, since this study is conducted at the aggregate level (CCS level), the dependent variable with censored observations are very few (i.e., the dataset includes only six observations with a value of zero and zero observations with a value of one). In this case, using the Tobit model or the OLS model would give similar results. Table 5.11 examines the effect of neighbourhood and farmers' characteristics factors on the adoption of ZT technology by using the OLS model (first column) and the Tobit model (second column). The results show no significant differences in the estimation between the OLS and the Tobit model. Therefore, in order to do the above tests and to apply the clustering approach, the OLS model is chosen in this study.

5.4.1 The Empirical Model Variables

The estimated empirical model derived from equation (12) is developed using the neighbourhood, farmer, and farm business characteristics variables regarding the adoption of ZT technology. The dependent variable, Zero Tillage Land (%), is the CCS's percentage of acreage planted using the ZT technology. A summary of the variable definitions and sources is presented in Table 5.2. Tables 5.3, 5.4, and 5.5 present the descriptive statistics for the variables for the year 1996, for the period from 1996 and 2001, and for the period from 1996 and 2006, respectively. Figure 5.2 presents two-way scatter plots that show the relationship between the dependent variable and the independent variables. The definitions, measurements, and expected signs of the independent variables are as follows.

Neighbourhood Effect: The neighbourhood effect in CCS_i at time t is explained in three variables: (1) The "Neighbourhood Effect–100 Km" variable is measured by: $(N_{100})_{it} = \sum \frac{(n_{100})_{j(t-1)}}{(d_{100})_{ij}}$ where the term $(n_{100})_{j(t-1)}$ is the number of farms in CCS_j who are located within a 100km radius (i.e. 0 $<$radius$\leq$ 100) from the centroid of CCS_i and adopted the ZT technology at time $t-1$, and the term $(d_{100})_{ij}$ is the distance, in kilometres, from the centroids of CCS_i to the centroid of CCS_j within a 100km radius (i.e. 0 $<$radius$\leq$ 100) from the centroid of CCS_i; (2) "Neighbourhood Effect–(100-200) Km" variable is measured by: $(N_{100-200})_{it} = \sum \frac{(n_{100-200})_{j(t-1)}}{(d_{100-200})_{ij}}$ where the term $(n_{100-200})_{j(t-1)}$ is the number of farms in CCS_j who are located within a radius between 100km and 200km (i.e. 100 $<$radius$\leq$ 200) from the centroid of CCS_i and adopted the ZT technology at time $t-1$, and the term $(d_{100-200})_{ij})$ is the distance, in kilometres, from the centroids of CCS_i to the centroid of CCS_j within a radius between 100km and 200km from the centroid of CCS_i; and (3) "Neighbourhood Effect–(200-300) Km" variable is measured by: $(N_{200-300})_{it} = \sum \frac{(n_{200-300})_{j(t-1)}}{(d_{200-300})_{ij}}$ where the term $(n_{200-300})_{j(t-1)}$ is the number of farms in CCS_j who are located within a radius between 200km and 300km (i.e. 200 $<$radius$\leq$ 300) from the centroid of CCS_i and adopted the ZT technology at time $t-1$, and the term $(d_{200-300})_{ij})$ is the distance, in kilometres, from the centroids of CCS_i to the centroid of CCS_j within a radius between 200km and 300km from the centroid of CCS_i.

A positive relationship is expected between the neighbourhood effect variables and the adoption of ZT technology (percentage of acreage planted using the ZT technology). This suggests that CCSs closer to other CCSs with relatively high adoption of ZT technology at time $t-1$ tend, themselves, to have higher ZT adoption at time t. Thus, it is expected that the impact of the neighbourhood variable on the adoption of ZT to decrease with the increase in the distance between CCSs. For instance, it is expected that the impact of "Neighbourhood Effect–100 Km"> "Neighbourhood Effect–(100-200) Km" > "Neighbourhood Effect–(200-300) Km" on the percentage of land planted with ZT technology. Visually, the scatterplots (a), (b), and (c) in Figure 5.2 show a positive relationship between the neighbourhood effect variables and the adoption of ZT technology.

In additional to its impact on learning process, the neighbourhood effect could capture a number of different factors which might affect the adoption of ZT. For instance, it could capture similar cultural or ethnic backgrounds in the same neighbourhood. It could also capture spatially related factors that are not explicitly captured in the regression (e.g., similar micro-climates and similarity in soil structure or in topography). In addition, the neighbourhood effect could capture social factors such as social acceptability of ZT (i.e., as the number of farmers who have adopted ZT increases, social pressures or community expectations to follow traditional tillage culture decreases, and, thus, the adoption of ZT increases in the same neighbourhood over time).

The Personal Characteristics of Farmers:

Age: Previous studies' results regarding the impact of age on the adoption of conservation tillage practices are contradictory (i.e., Warriner and Moul (1992) found a positive while Gould et al. (1989) and Norris and Batie (1987) found a negative correlation between age and the adoption of conservation tillage practices) and in some cases insignificant (e.g., Neill and Lee, 1999). This is because younger farmers may seek and use new information to a greater degree than older farmers, while older farmers may have longer farming experience and are more aware of soil degradation problems and available solutions than younger farmers. In this study, age is measured by the percentage of farmers aged 35 or younger in every CCS. Although the scatterplot f in figure 5.2 shows a positive relationship between the "Age" variable and the adoption of ZT, no prior expectation is assumed for the sign of the parameter on the "Age" variable.

Education: Previous studies (e.g., Rahm and Huffman, 1984; Warriner and Moul, 1992) found a positive impact of education levels on the adoption of conservation tillage practices. According to these studies, high education level is often assumed to be correlated with access to more information and with high level of knowledge. In this study, education is measured by the percentage of poeple with a university degree in each CCS. A positive relationship is expected between the "Education" variable and the adoption of ZT. Visually, the scatterplot (g) in Figure 5.2 shows a positive relationship between the "Education" variable and the adoption of ZT technology.

Off-farm Employment (Off-farm): Assessments by previous studies of the impact of off-farm employment on the adoption of conservation tillage practices, reveal both positive (e.g., Fuglie, 1999) and negative (e.g., Ervin and Ervin, 1982; Okoye, 1998; Swinton 2000) relationships. This is because the role of off-farm activity can be viewed in two ways. First, off-farm income can provide additional resources for financing conservation tillage expenses. Alternately, off-farm income can diminish farmer priority for agriculture and, thus, reduce interest in implementing new conservation practices. In this study, off-farm employment is measured by the percentage of farmers in the CCS reporting 20 hours or more of off-farm work per week. Although the scatterplot (h) in figure 5.2 shows a positive relationship between the "Off-farm Employment" variable and the adoption of ZT, no prior expectation is assumed for the sign of the coefficient on this variable.

Farm Business Characteristics:

Owned Farm (%): It is generally held that owned land is better maintained by farmers than rented land. Previous studies on conservation tillage (e.g., Clay et al., 1998; Neill and Lee, 1999) support this hypothesis and show a positive relationship between owned land and conservation tillage adoption. In this study, "owned-farm" variable is measured by the percentage of owned farms in each CCS. A positive relationship is expected between the "Owned-farm" variable and the adoption of ZT technology. Visually, the scatterplot (d) in Figure 5.2 shows a positive relationship between the "Owned-farm" variable and the adoption of ZT.

Large Farm (%): Previous studies (e.g., Carlson et al., 1981; Lasley and Nolan, 1981; Smit and Smithers, 1992) on conservation practices found a positive correlation between the farm size and adoption of such farming practices. Owners of larger farms are more willing to invest in new practices since larger farms are generally associated with greater wealth. In this study, "Farm-size" variable is measured by the percentage of farms 1,600 acres or larger in each CCS. A positive relationship is expected between this variable and the adoption of ZT technology. Visually, the scatterplot (e) in Figure 5.2 shows a positive relationship between the "Farm-size" variable and the adoption of ZT.

Distance to Nearest Research Station (km) Previous studies on conservation tillage practices (e.g., Nowak and Korsching, 1982; Rahm and Huffman, 1984; Westra and Olson, 1997) found that farmers' interactions with research station agencies positively influenced the adoption of such farming practices. This effect occurs because research extension provides farmers with the information and assistance regarding the new technologies in an effective and comprehensible manner. In this study, it is expected that the shorter the travel distance between a farmer location and a research station, the greater the probability of interaction with station's agents, and the greater the likelihood of adopting the ZT technology. This variable is measured by the distance, in kilometres (as a proxy for transportation cost), from each CCS centroid to the closest research station or substation location centroid on the Prairies.[1] A negative relationship is hypothesized between this variable and the adoption of ZT technology. Visually, the scatterplot (i) in Figure 5.2 shows a negative relationship between the "Distance to Nearest Research Station" variable and the adoption of ZT.

Distance to Nearest Urban Centre (km): Represents the distance to the nearest urban centre (i.e., Census Agglomerations (CA)/Census Metropolitan Ar-

[1]Provincially, Prairie research stations and substations are located as follows: (1) Lacombe, Beaverlodge, Lethbridge, Vermillion, Onefour, Stavely, and Vauxhall at Alberta, (2) Saskatoon, Swift Current, Scott, Melfort, Indian Head, and Regina at Saskatchewan, and (3) Brandon, Winnipeg, Morden, and Glenlea at Manitoba (AAFC 2010).

eas (CMA)) of any size. In this study, it is expected that farmers located closer to an urban centre are more likely to be interested in non-farming activities, which diminishes their priority for agriculture and, thereby, reduces their interest in adopting new technologies. This distance is measured, in kilometres, from each CCS centroid to the urban centre centroid. A positive relationship is hypothesized between this variable and the adoption of ZT technology. Opposite to our expectation, the scatterplot (j) in Figure 5.2 shows a negative relationship between the "Distance to Nearest Urban Centre" variable and the adoption of ZT.

Soil Type (Brown Soil (%)): The Canadian Prairies area is divided into five soil–climate zones: Black, Dark Grey, Grey, Dark Brown and Brown. In general, the Brown soil zone is less moist than the other soil zones (Zentner et al., 2002). Campbell et al. (2002) found that the adoption of ZT technology on the Prairies is higher in the more humid soil areas (i.e., Black, Dark Grey, Grey and Bark-Brown soil zones) than in the Brown soil zone. According to the authors, this could be due to the greater likelihood for the more humid soils to be re-cropped for continuous periods without risk of yield depression caused by stresses like drought. In this study, soil type is divided into two variables: the "Black–DBrown Soil" variable including the Black, Dark Grey, Grey, Dark Brown soil type zones and the "Brown Soil" variable including the Brown soil type zone. Soil type variables are measured by the percentage area of each soil type zone in each CCS. A negative relationship is expected between the "Brown Soil" variable and the adoption of ZT technology. Since these two variables add to one, the variable "Black–DBrown Soil" is dropped from the analysis to avoid perfect collinearity situation with the "Brown Soil" variable. However, visually, the scatterplot (k) in Figure 5.2 shows a slightly positive relationship between the "Brown Soil" variable and the adoption of ZT technology.

Soil Erosion (Erosion-High Risk (%)): Based on the rate of soil loss, the AAFA (2010) divided the Prairie area into five soil erosion classes: "Very Low" is when an area loses less than 6 tonnes per hectare per year, "Low" loses 6 to 11 t $ha^{-1}yr^{-1}$, "Moderate" loses 11 to 22 t $ha^{-1}yr^{-1}$, "High" loses 22 to 33 t $ha^{-1}yr^{-1}$ and "Very High" loses more than 33 t $ha^{-1}yr^{-1}$. In this study, soil erosion, measured by the percentage area of each soil erosion class in each CCS in 1991, is divided into two variables: the "Erosion-Low Risk" variable including the Very Low, Low and Moderate soil erosion classes and the "Erosion-High Risk" variable including the High and Very High soil erosion classes. Since these two variables add to one, the variable "Erosion-Low Risk" was dropped from the analysis to avoid perfect collinearity situation with "Erosion-High Risk" variable. A positive relationship is expected between the "Erosion-High Risk" variable and the adoption of ZT technology. Visually, the scatterplot (l) in Figure 5.2 shows a slightly positive relationship between the "Erosion-High Risk" variable and the adoption of ZT technology..

The empirical model does not explicitly control for some unobserved features that vary little over time and are specific to each province (e.g., access to highways and railways). For that, provincial dummies (i.e., Alberta (AB), Saskatchewan (SK), and Manitoba (MB)) are included to control for common factors within the same province (to avoid perfect collinearity situation that leads to the dummy variable trap, MB is omitted). Similarly, the adoption of ZT may shift over time because of factors that are not explicitly controlled in the model (e.g., government regulatory and/or tax policies at the national level, general economic condition, and technology change). To control for these factors, time dummies (i.e, 1996 (t96), 2001 (t01), and 2006 (t06)) are included in the analysis (the dummy variable t96 is omitted to avoid perfect collinearity situation).

As indicated above, time-dummy variables are included in this analysis to capture unobserved time-varying effects that are common to the three Prairies provinces. Indeed, they capture the effect of factors like economic condition on the adoption of ZT. One of the economic factors that the time-varying variables capture is the impact of the change in the ratio of the fuel to the Roundup prices (fuel/Roundup price ratio) on the adoption of ZT. To explicitly capture the effect of the fuel/Roundup price ratio on the adoption of ZT, a new variable called fuel/Roundup ratio could be added to the regression. This variable could be measured by the ratio of the fuel price index to the Roundup price index in 1996, 2001 and 2006.

5.5 Data Source

Data by census consolidated subdivision (CCS) for Alberta, Saskatchewan and Manitoba from 1991 to 2006 are used for this study. Zero tillage (acres and number of farms using ZT), age, off-farm, owned-farm, and farm-size data are available from the Agriculture Division of Statistics Canada. Education data is available from the Population Division of Statistics Canada. Soil type data is from the Department of Soil Science at the University of Saskatchewan. Soil erosion data is from the Agriculture and Agri-Food Canada (AAFC). The distance variables are calculated by using ESRI ArcGIS software version 9.3 available in the Canada Rural Economy Research Lab (C-RERL) in the Department of Bioresource (PBE) at the University of Saskatchewan.

Census data contains agricultural, demographic, economic, and socio–economic information for more than 2000 consolidated subdivisions of Canada. In this study, the variables are tabulated within constant boundaries for, AB, SK, and MB, and for the four census, 1991, 1996, 2001, and 2006. Census data are available from Statistic Canada – Agriculture and Population Census – every five years, thus, this study covers the following years: 1991, 1996, 2001, and 2006.

5.6 Results

The specification of the model in equation (12) accounts for the effect of neighbourhood, farmer personal characteristics and farm business characteristics on the percentage of land planted with zero tillage. Including all these variables in the analysis could introduce a multicollinearity problem while omitting some of these variables could introduce an omitted variable problem. Multicollinearity occurs when there is a linear relationship between two or more predictor variables in a multiple regression model. Omitted variable problem occurs when some of the explanatory variables are correlated with the error term, which leads to biased results.

To assess for multicollinearity and omitted variable problems, four alternative specifications are examined in this section. Since the neighbourhood effect variables are our primary focus, we begin with a parsimonious model, model 1, that includes only the neighbourhood effect variables, and provincial and year dummies (see Table 5.9 first column). Model 2 adds to model 1 the distances to the nearest research station and urban centre, soil type, and soil erosion risk variables (see Table 5.9 second column). Models 1 and 2 mitigate the multicollinearity problem since all variables, except that for the neighbourhood effect variables, are exogenously determined. Model 3 adds to model 2 the tenure status and farm size variables (see Table 5.9 third column). Finally, model 4 (the full model) adds to model 3 farmer age, education, and off-farm work variables (see Table 5.9 fourth column). Models 3 and 4 include additional explanatory variables to the analysis to address the problem of possible key variables omission. The overall results show that the effects of neighbourhood variables on the percentage of land planted to zero tillage are not altered by the change in the specification in models 1 to 4.

Model 1, reported in Table 5.9 (first column), includes only the neighbourhood effect variables, and provincial and year dummies. Results of model 1 show that the "Neighbourhood effect–100km" coefficient has the expected positive effect on the percentage of land under ZT, and is statistically significant at 0% significance level. This suggests that the CCS_i that is located at a distance between 0 to 100 kilometres away from the CCS_j with relatively high adoption of ZT technology at time $t-1$, tends, itself, to have higher ZT adoption at time t. Neighbourhood Effect – (100-200 Km) and Neighbourhood Effect – (200-300 Km) variables are found to be insignificant. Provincial and time dummies variables are found to be significant.

Model 2, reported in Table 5.9 (second column), adds to model 1 the time-invariant variables (i.e., the distances to the nearest research station and urban centre, brown soil type and high soil erosion risk variables). Most importantly, the results in Table 5.9 (second column) show that the "Neighbourhood effect–100km" variable maintains its positive and significant effect on the percentage of land under ZT, even after controlling all time-invariant variables. The time-invariant variables are found to be insignificant in Model 2.

Model 3, reported in Table 5.9 (third column), adds to model 2 the "Owned Farm" and "Large Farm" variables. Results of model 3 show that "Neighbourhood effect–100km" keeps its positive and significant effect on the percentage of land under ZT. "Owned Farm" and "Large Farm" variables significantly and positively influence the percentage of land under ZT. The "Distance to Research Station" coefficient becomes significant at 10% significance level and has the expected sign. The "Brown Soil" and "Erosion-High Risk" coefficients become each significant at 5% significance level and have the expected sign.

Model 4 (the full model), reported in Table 5.9 (fourth column), adds to model 3 the "Age-Young Farmer", "Education-Uni. degree" and "Off-farm" variables. Results of Model 4 show that neighbourhood effect -100km, education, owned-farm, farm size, and soil erosion-high risk level significantly and positively influence the percentage of land under ZT technology. Distance to research station and brown soil type are found to be significantly and negatively impact the percentage of land under ZT. Neighbourhood effect (100-200 Km), neighbourhood effect (200-300 Km), age, off-farm employment, and distance to nearest urban centre variables are found to be insignificant. Provincial and time dummies are found to be significant.

In sum, the results of the empirical analysis show that the "Neighbourhood effect -

100km" coefficient is significant at 0% significant level, and varies little in value across models 1–4. Thus, we strongly support the positive effect of the neighbourhood effect on the adoption of ZT technology, indicating that the information released on the performance of ZT from previous adopters, and the impact of the other factors (e.g., similar cultural or ethnic background, similar micro-agronomic conditions and the social acceptance of the ZT concept) that the neighbourhood effect variable could capture, positively influence the adoption of ZT during the period from 1996 to 2006.

Note that to be able to separate between the impact of the information released on the performance of ZT from previous adopters and the impact of the other factors that the neighbourhood effect variable could capture, a richer data set will be needed to sort out the importance of each of these factors in the same neighbourhood.

Model 4 (the full model), reported separately in Table 5.10, is chosen in this study. Because the explanatory variables are measured in different units of measurement, they have widely varying mean and range, indicating that the resulting coefficients in Table 5.10 can't be directly compared. Therefore, to account for the differences in the units of measurement of the explanatory variables, and to answer the question of which of the explanatory variables have greater effect on the dependent variable, the standardized coefficients are estimated and presented in Table 5.10 (last column). Standardization of the coefficient puts all explanatory variables on a common scale of unit that is measured in standard deviations instead of the unit of the variable. In this case, because the coefficients are in standardized units we can compare these coefficients to assess the relative strength of each of the explanatory variables.

The standardized coefficients can be estimated before running the regression by transforming the dependent and the independent variables into standardized variables (standard scores or z-scores). A standardized variable is a variable that has been rescaled to have a mean of zero and standard deviation of one. A standardized variable is given by $x^* = (x - \bar{x})/sd_x$, where $\bar{x}$ is the mean of the variable x, and sd_x is the standard deviation of the variable x. The standardized coefficients can also be estimated after running the regression by using the following formula: standardized coefficient $= \frac{\text{coefficient} \times \text{standard deviation of the explanatory variable}}{\text{standard deviation of the dependent variable}}$.

The standardized coefficient estimation in Table 5.10 shows that a one standard deviation increase in the neighbourhood effect-100km variable leads to 0.33 standard deviation increase in the percentage of land under ZT.[2] The other variables in Table 5.10 are interpreted similarly.

Provincial and time dummies variables are interpreted as follows: compared to Manitoba, if the province is Saskatchewan, the percentage of land planted to ZT increases by 0.18 standard deviation, and if the province is Alberta, the percentage of land under ZT increases by 0.23 standard deviation; compared to 1996 (t96), if the years are 2001 (t01) and 2006 (t06), the percentage of land under ZT technology increases by 0.14 and 0.32 standard deviation, respectively.

[2]Since this study uses random-effects GLS model, the coefficients include both the within-entity and between-entity effects. In this case, a coefficient can be interpreted as the change in the dependent variables brought out by the change in the independent variables across time and between entities.

5.7 Summary and Conclusion

Zero tillage technology is notable for its complexity and irreversibility, which increases the effort and time required to learn about its performance and makes waiting valuable. Waiting enables farmers to acquire more information on the performance of ZT from neighbours who have already used the technology (neighbourhood effect), which in turn increases farmers stock of knowledge and, thus, positively influences the adoption of ZT.

This study presents a model of heterogeneous farmers' decision-making under a waiting option framework. The model assumes that, in a given period, the decision to adopt zero tillage technology or to keep using the traditional one is derived from the maximization of the relative return function. At the end of each period, information about the performance of zero tillage is realized from farmers who have already used the technology. Through social communication, this information is added to the stock of knowledge of potential adopters and used in their decision-making in the next period. Analytical results of the differentiated farmer model show that, given the output price and the relative costs of production under TT and ZT, the information released on the performance of ZT from previous adopters positively influences the future adoption of ZT.

The theoretical predictions are then empirically tested using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for Alberta, Saskatchewan and Manitoba. The neighbourhood effect is used as a proxy for the information released from previous adopters of ZT, and for the common factors that are associated with the same neighbourhood. Farmers' heterogeneity is captured by two sets of variables: farmers' personal characteristics, including age, education and off-farm employment variables; and farm business characteristics, including farm size, tenancy, distance to research station and urban centre, and soil erosion and type conditions. In addition, provincial and time dummy variables are introduced in the analysis to control for the unobserved features that are not explicitly captured by the model.

To correct for spatial correlation problem the empirical model is estimated by using the clustering approach. The multicollinearity and omitted variable problems are addressed by examining four alternative specifications. The evidence from the empirical analysis in models 1–4 strongly supports the positive effect of the neighbourhood effect on the adoption of ZT technology, indicating that the results are robust to various specification changes.

The full empirical model is developed using the neighbourhood effect, farmer and farm business characteristics variables regarding the adoption of ZT technology. Results of the full model show that neighbourhood effect, owned-farm, farm size, education and high soil erosion risk significantly and positively influence the adoption of ZT technology. Distance to research station and brown soil type significantly and negatively impact ZT adoption. Neighbourhood effect–(100-200 Km), neighbourhood effect–(200-300 Km), age, off-farm employment, and distance to nearest urban centre variables are found to be insignificant. Provincial dummies show that, compared to Manitoba, if the province is Saskatchewan or Alberta the adoption of ZT increases because of specific features related to each province. Time dummy variables indicate that, compared to 1996, if the year is 2001, or 2006, the adoption of ZT increases because of factors such as changes in government regulatory and/or tax policies at the national level and technology change.

The evidence from the empirical analysis supports the positive effect of the neighbourhood effect on the adoption of ZT technology, suggesting that the information released on the performance of ZT from previous adopters positively influences the future adoption of ZT. This result is consistent with the theoretical prediction of our model that farmers may wait to acquire more information on the performance of ZT from neighbours who have already used the technology before they decide to switch from TT to ZT technology to mitigate the impact of uncertainty and sunk cost.

Note that the information released on the performance of ZT from previous adopters is one possible explanation for the impact of the neighbourhood effect variable on the adoption of ZT. This variable can also explain the impact of other factors (e.g., cultural or ethnic backgrounds, similar agronomic conditions and the social acceptability of ZT concept) in the same neighbourhood on the adoption of ZT.

Table 5.2: Data Definition and Source

	Definition	Source
Dependent Variable		
Zero Tillage Land (%)	Percentage of land, in acres, planted with zero tillage technology in every CCS	ADSC
Independent Variable		
Neighbourhood Effect–100 Km	For CCS_i at time t, the "Neighbourhood Effect" is measured by the sum of the farms that adopted the zero tillage technology at time $t-1$ in CCS_j divided by the distance from CCS_i to CCS_j within a circle of a radius equal to 100 km. The distance is measured in km from the centroid of CCS_i to the centroid of CCS_j.	ADSC & CRERL
Neighbourhood Effect–(100-200 Km)	Similar definition to the Neighbourhood Effect–100 Km, except that the area is within a circle of a radius equal to 100-200km	ADSC & CRERL
Neighbourhood Effect–(200-300 Km)	Similar definition to the Neighbourhood Effect–100 Km, except that the area is within a circle of a radius equal to 200-300km	ADSC & CRERL
Dist. to Nearest Research Station (Km)	The distance in km from the centroid of every CCS to the nearest research station location centroid	CRERL
Dist. to Nearest urban Centre (Km)	The distance in km from the centroid of every CCS to the nearest urban centre centroid	CRERL

Continued . . .

Table 5.2 (Continued)

Brown Soil (%)	Percentage of the brown soil type area in every CCS	DSC
Erosion - High Risk (%)	Percentage of the area under the high risk soil erosion class in 1991	AAFC
Owned Farm (%)	Percentage of owned farms in every CCS	ADSC
Large Farm (%)	Percentage of farms 1,600 acres or larger in each CCS	ADSC
Age –Young Farmer (%)	Percentage of farmers age 35 or younger in every CCS	ADSC
Education– Univ. degree (%)	Percentage of people with a university degree in every agricultural CCS	PDSC
Off–Farm (%)	Percentage of farmers reporting 20 hours per week of off-farm work in every CCS	ADSC
MB, SK and AB	Provincial dummy variable for Manitoba, Saskatchewan and Alberta, respectively	
t96, t01, t06	Year dummy: 1996, 2001 and 2006, respectively	

ADSC: Agriculture Division of Statistics Canada
PDSC: Population Division of Statistics Canada
CRERL: Canada Rural Economy Research Lab at University of Saskatchewan
DSC: Department of Soil Science at the University of Saskatchewan
AAFC: Agriculture and Agri-Food Canada

Table 5.3: Descriptive Statistics–Year: 1996

Variable	Mean	Std. Dev.	Min	Max
Zero Tillage Land (%)	0.12	0.10	0.00	0.53
Neighbourhood Effect 100 Km	9.99	5.58	0.00	25.13
Neighbourhood Effect (100-200 Km)	9.77	4.76	0.11	19.81
Neighbourhood Effect (200-300 Km)	7.54	3.32	0.00	15.08
Owned Farm (%)	0.63	0.09	0.22	0.84
Large Farm (%)	0.21	0.12	0.02	0.62
Age –Young Farmer (%)	0.16	0.04	0.08	0.29
Education– Univ. Degree (%)	0.06	0.03	0.00	0.19
Off–Farm (%)	0.22	0.06	0.05	0.38
Sample Size	467			

Table 5.4: Descriptive Statistics–Year: 1996-2001

Variable	Mean	Std. Dev.	Min	Max
Zero Tillage Land (%)	0.17	0.13	0.00	0.79
Neighbourhood Effect – 100 Km	11.74	6.48	0.00	27.66
Neighbourhood Effect – (100-200 Km)	11.52	5.78	0.11	25.71
Neighbourhood Effect – (200-300 Km)	8.97	4.22	0.00	21.45
Owned Farm (%)	0.63	0.08	0.21	0.84
Large Farm (%)	0.23	0.12	0.02	0.68
Age –Young Farmer (%)	0.14	0.04	0.03	0.29
Education– Univ.degree (%)	0.06	0.03	0.00	0.22
Off–Farm (%)	0.28	0.09	0.05	0.60
Sample Size	934.00			

Table 5.5: Descriptive Statistics–Year: 1996-2006

Variable	Mean	Std. Dev.	Min	Max
Zero Tillage Land (%)	0.24	0.18	0.00	0.81
Neighbourhood Effect–100 Km	13.42	7.36	0.00	30.08
Neighbourhood Effect–(100-200 Km)	13.33	6.92	0.11	31.67
Neighbourhood Effect–(200-300 Km)	10.44	5.15	0.00	24.52
Owned Farm (%)	0.64	0.09	0.21	0.98
Large Farm (%)	0.25	0.13	0.02	0.70
Age –Young Farmer (%)	0.13	0.04	0.00	0.29
Education– Univ. degree (%)	0.07	0.03	0.00	0.33
Off–Farm (%)	0.31	0.09	0.05	0.60
Distance to Nearest Research Station	93.85	51.21	2.00	425.00
Distance to Nearest Urban Centre	80.84	40.81	0.00	356.00
Brown Soil (%)	15.62	33.68	0.00	100.00
Erosion – High Risk (%)	0.47	2.61	0.00	34.37
Sample Size	1401.00			

Table 5.6: Breusch and Pagan Lagrangian Multiplier (LM) Test for Random Effects vs Simple OLS

Zero Tillage Land (ccs,t) = Xb + u(ccs)+ e(ccs,t)		
	var	sd = sqrt(Var)
Zero Tillage Land	0.0317	0.1782
e	0.0053	0.0730
u	0.0051	0.0711
Test: Var(u) = 0		
chi2(1) = 286.60		
Prob > chi2 = 0.0000		

Table 5.7: Variance Inflation Factor Test (VIF): Check for Multicollinearity

Explanatory Variable	VIF	1/VIF
Neighbourhood Effect – (100-200 Km)	7.17	0.13938
t06	6.1	0.163848
Neighbourhood Effect – (200-300 Km)	5.78	0.172873
Neighbourhood Effect – 100 Km	3.88	0.257785
Off–Farm (%)	3.38	0.296265
t01	3.22	0.310959
Large Farm (%)	2.78	0.359586
SK	2.72	0.367297
Dist. to Nearest urban Centre (km)	1.77	0.564826
Dist. to Nearest Research Station (km)	1.73	0.578037
Age –Young Farmer (%)	1.65	0.604868
AB	1.62	0.6175
Brown Soil (%)	1.6	0.625944
farm–owned	1.45	0.688521
Eduction– Univ. degree (%)	1.24	0.803577
Erosion - High Risk (%)	1.08	0.923874
Mean VIF	2.95	

Table 5.8: Testing for Panel Data Heteroskedasticity: The Likelihood Ratio Test

The Null is Homoskedasticity (or constant variance)						
Model	Obs	ll(null)	ll(model)	df	AIC	BIC
.	1401	.	1198.73	17	-2363.46	-2274.296
hetero	1401	.	1198.73	17	-2363.46	-2274.296
LR chi2(17) = -0.00						
Prob > chi2 = 1.0000						

Table 5.9: Results: Estimating the Impact of Neighbourhood Effect and Farmer Characteristics on the Percentage of Land Planted with Zero Tillage

Explanatory Variable	Model 1 Coeffic.	Model 2 Coeffic.	Model 3 Coeffic.	Model 4 Coeffic.
Neighbourhood Effect (100 Km)	0.0086***	0.0083***	0.0081***	0.0080***
Neighbourhood Effect (100-200 Km)	0.0040	0.0037	0.0029	0.0031
Neighbourhood Effect (200-300 Km)	0.0043	0.0047	0.0045	0.0043
SK	0.0660**	0.0707***	0.0651***	0.0668***
AB	0.1156***	0.1212***	0.1246***	0.1218***
t01	0.0546***	0.0556***	0.0527***	0.0534***
t06	0.1353***	0.1372 ***	0.1226***	0.1225***
Dist. to Nearest Research Station (km)		-0.0004	-0.0004*	-0.0004*
Dist. to Nearest urban Centre (km)		0.0003	0.0002	0.0002
Brown Soil (%)		-0.0001	-0.0004**	-0.0004**
Erosion - High Risk (%)		0.0017	0.0020**	0.0021**
Owned Farm (%)			0.1290***	0.1325***
Large Farm (%)			0.2086***	0.2175***
Age –Young Farmer (%)				0.0504
Education – Univ. degree (%)				0.2025*
Off–Farm (%)				-0.0011
Constant	-0.0952***	-0.0759***	-0.1770***	-0.2029***
R^2–Overall	0.6270	0.6389	0.6562	0.6600
R^2–between	0.5100	0.5333	0.5672	0.5749
R^2–within	0.7600	0.7593	0.7578	0.7568
Sigma–u	0.0790	0.0787	0.0728	0.0711
Sigma–e	0.0730	0.0730	0.0730	0.0730
rho	0.5400	0.5200	0.4980	0.4870
$p > chi^2$	0.0000	0.0000	0.0000	0.0000
chi^2	1047	2300	1758	2109
Observations	1401	1401	1401	1401

*** significant at 1%; ** significant at 5%; and * significant at 10%.
Std. Err. adjusted for 55 clusters in CD

Table 5.10: Model 4: Estimating the Impact of Neighbourhood Effect and Farmer Characteristics on the Percentage of Land Planted with Zero Tillage

Explanatory Variable	Coeff.	Robust Std. Err.	P–Value	Standard. Coeff.
Neighbourhood Effect – 100 Km	0.0080***	0.0020	0.0000	0.3289***
Neighbourhood Effect – (100-200 Km)	0.0031	0.0024	0.1940	0.1217
Neighbourhood Effect – (200-300 Km)	0.0043	0.0028	0.1350	0.1231
Dist. to Nearest Research Station (km)	-0.0004*	0.0002	0.1010	-0.1135*
Dist. to Nearest urban Centre (km)	0.0002	0.0003	0.4630	0.0428
Brown Soil (%)	-0.0004**	0.0002	0.0290	-0.0737**
Erosion - High Risk (%)	0.0021**	0.0010	0.0310	0.0306**
Owned Farm (%)	0.1325***	0.0476	0.0050	0.0672***
Large Farm (%)	0.2175***	0.0925	0.0109	0.1598***
Age –Young Farmer (%)	0.0504	0.0920	0.5840	0.0121
Education– Univ. degree (%)	0.2025*	0.1035	0.0500	0.0382*
Off–Farm (%)	-0.0011	0.0806	0.9890	-0.0006
SK	0.0668***	0.0239	0.0050	0.1813***
AB	0.1218***	0.0188	0.0000	0.2337***
t01	0.0534***	0.0186	0.0040	0.1412***
t06	0.1225***	0.0283	0.0000	0.3243***
Constant	-0.2029***	0.0551	0.0000	

*** significant at 1%, ** significant at 5% and * significant at 10%.

Std. Err. adjusted for 55 clusters in CD

Table 5.11: Regression Comparison: OLS and Tobit
Estimating the Impact of Neighbourhood Effect and Farmer Characteristics on the Percentage of Land Planted with Zero Tillage

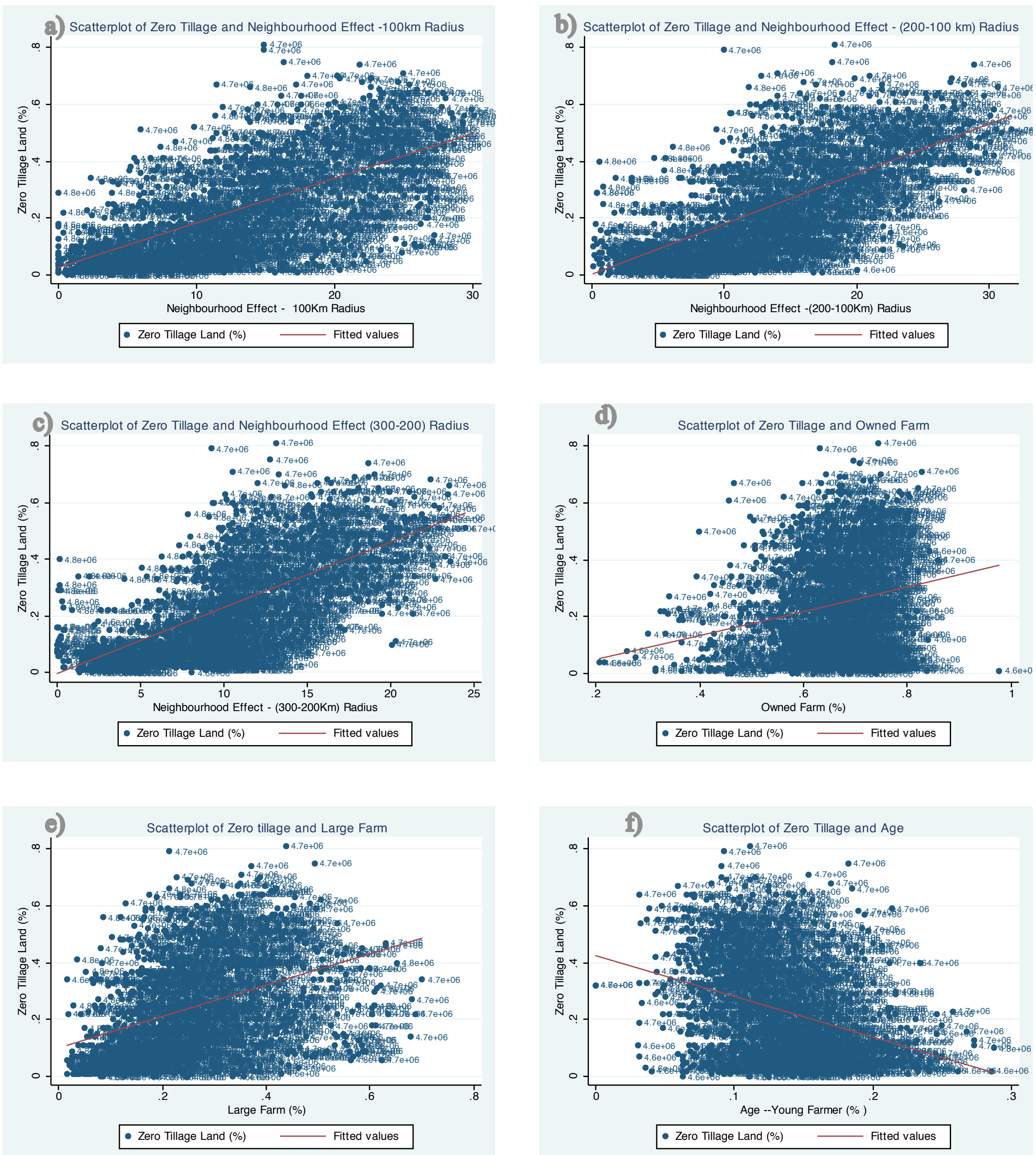
Explanatory Variable	OLS: Coeffi. b/se/p	Tobit: Coeffi. b/se/p
Neighbourhood Effect – 100 Km	0.0080***	0.0080***
	-0.0008	-0.0008
	[0.000]	[0.000]
Neighbourhood Effect – (100-200 Km)	0.0031**	0.0031**
	-0.0013	-0.0013
	[0.014]	[0.014]
Neighbourhood Effect – (200-300 Km)	0.0043***	0.0042***
	-0.0015	-0.0015
	[0.004]	[0.004]
Dist. to Nearest Research Station (km)	-0.0004***	-0.0004***
	-0.0001	-0.0001
	[0.000]	[0.000]
Dist. to Nearest urban Centre (km)	0.0002	0.0002
	-0.0001	-0.0001
	[0.137]	[0.133]
Brown Soil (%)	-0.0004***	-0.0004***
	-0.0001	-0.0001
	[0.007]	[0.007]
Erosion - High Risk (%)	0.0021	0.0021
	-0.0016	-0.0016
	[0.180]	[0.179]
Owned Farm (%)	0.1325***	0.1322***
	-0.0447	-0.0448
	[0.003]	[0.003]
Large Farm (%)	0.2175***	0.2148***
	-0.0426	-0.0431
	[0.000]	[0.000]

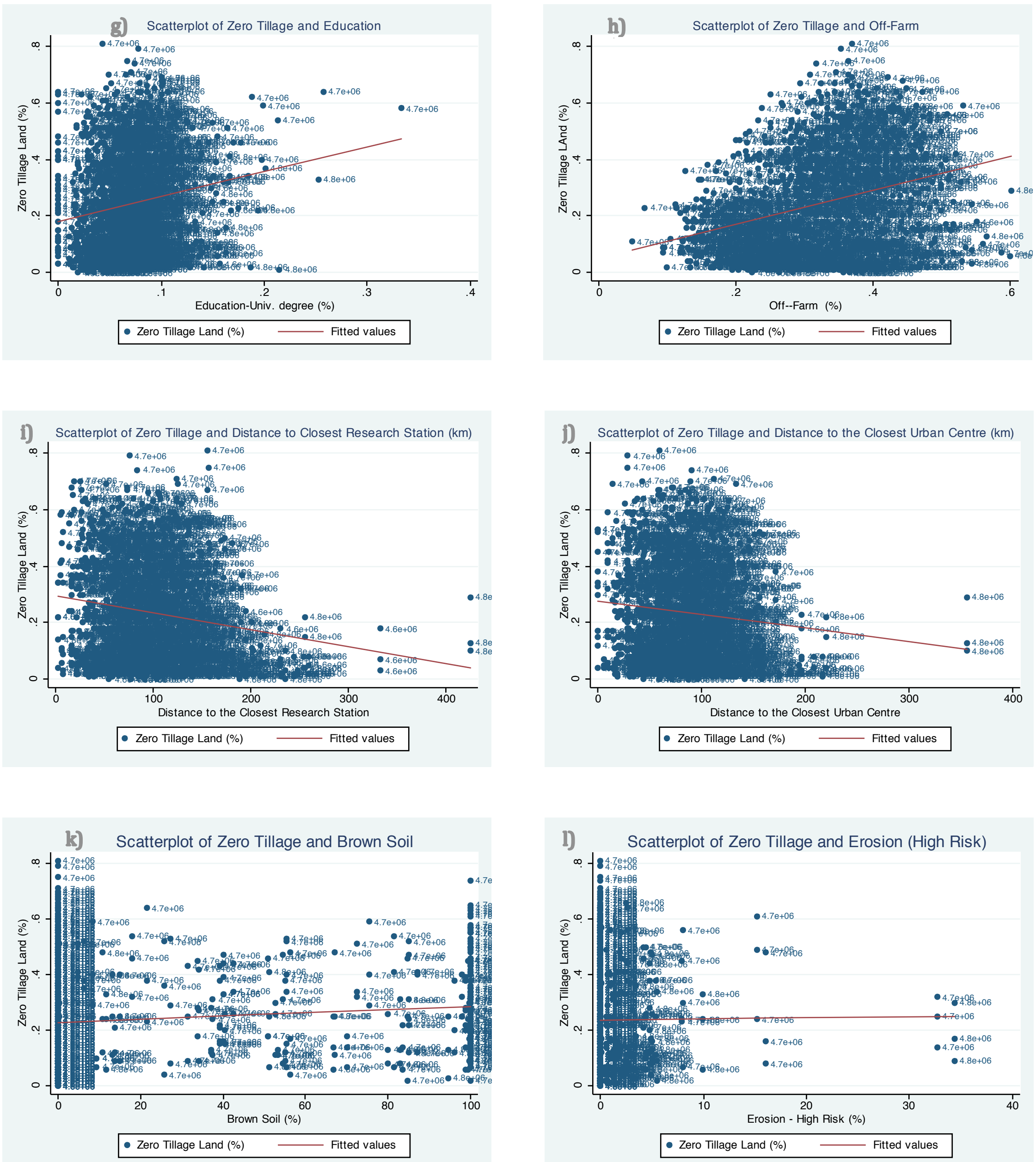
Continued . . .

Table 5.11 (Continued)

Age –Young Farmer (%)	0.0504	0.051
	-0.0785	-0.0783
	[0.521]	[0.515]
Eduction– Univ. degree (%)	0.2025**	0.2022**
	-0.0907	-0.0912
	[0.026]	[0.027]
Off–Farm (%)	-0.0011	-0.0034
	-0.0536	-0.0539
	[0.984]	[0.950]
SK	0.0668***	0.0687***
	-0.0122	-0.0123
	[0.000]	[0.000]
AB	0.1218***	0.1234***
	-0.0143	-0.0144
	[0.000]	[0.000]
t01	0.0534***	0.0537***
	-0.0094	-0.0094
	[0.000]	[0.000]
t06	0.1225***	0.1236***
	-0.0139	-0.0139
	[0.000]	[0.000]
Constant	-0.2029***	-0.2040***
	-0.0382	(0.03830
	[0.000]	[0.000]
Observations	1401	1401
p	0	0
chi^2	3477.3	3509.7

Figure 5.2: Scatterplots: The Relationship between the Dependent Variable and the Independent Variables




g) Scatterplot of Zero Tillage and Education
Zero Tillage Land (%)
Education-Univ. degree (%)
Zero Tillage Land (%)
Fitted values
h) Scatterplot of Zero Tillage and Off-Farm
Zero Tillage LAnd (%)
Off--Farm (%)
Zero Tillage Land (%)
Fitted values
i) Scatterplot of Zero Tillage and Distance to Closest Research Station (km)
Zero Tillage Land (%)
Distance to the Closest Research Station
Zero Tillage Land (%)
Fitted values
j) Scatterplot of Zero Tillage and Distance to the Closest Urban Centre (km)
Zero Tillage Land (%)
Distance to the Closest Urban Centre
Zero Tillage Land (%)
Fitted values
k) Scatterplot of Zero Tillage and Brown Soil
Zero Tillage Land (%)
Brown Soil (%)
Zero Tillage Land (%)
Fitted values
l) Scatterplot of Zero Tillage and Erosion (High Risk)
Zero Tillage Land (%)
Erosion - High Risk (%)
Zero Tillage Land (%)
Fitted values

Chapter 6

Summary and Conclusion

One of the major innovations in Canadian agriculture over the last five decades has been the introduction of conservation tillage. Conservation tillage (CT) was mainly introduced to combat land degradation and promote agricultural sustainability. Land degradation reduces crop yields through losses in nutrients, water storage capacity, and organic matter.

CT – a term that includes minimum or mulch tillage and zero-tillage (ZT) – is an innovation package that consists of new management practices, herbicides, equipment and crop mixes. The development of this technology involved pioneer farmers, engineers, scientists, and farm associations. By the end of the 1970s, CT, with all its components, had taken shape and was ready for adoption. But the adoption of this technology did not occur on any major scale before the 1990s.

The development and adoption path of CT can be divided into three time periods. Between the 1930s and 1940s, intensive tillage combined with a period of severe drought and accompanying dust storms lead to wide-spread land degradation on the Prairies. To combat this degradation, the federal government established the

Prairie Farm Rehabilitation Administration (PFRA), which worked together with experimental farms, universities, farmers and farm associations to develop more sustainable practices. The result of these efforts was the introduction of trash–cover, ploughless fallow, and strip farming practices using one–way discers, duckfoot cultivators, the Morris rod weeder, and the wide–blade cultivator. Between the 1950s and early 1970s, there was a move toward larger farms and wider equipment, which made trash and strip farming practices inconvenient. During this period, the herbicide paraquat and the no–till drill seeder were introduced on the Prairies. However, the high price and inadequate control of broadleaf weeds by paraquat, and the cost and limited success of no–till drills were regarded as deterrents to the production of a crop under a low–disturbance direct seeding system. In addition, policy factors such as the Canadian Wheat Board's delivery quota system encouraged farmers to convert seeded areas to summerfallow using tillage practices.

By the end of the 1970s, factors such as an increase in grain prices, removal of the CWB's delivery quota, the introduction of the herbicide glyphosate by Monsanto, improvements in the no–till drill, and the introduction of new varieties of oilseeds and pulses all contributed to the development of conservation tillage. During the 1980s and 1990s, the establishment of the conservation tillage associations, improvements in air seeder and harvesting equipment and a decrease in the price of glyphosate and interest rates on borrowed capital all played a role in the adoption of CT, and particularly ZT, on the Prairies.

Although some farmers had adopted ZT by the late 1970s and had found it profitable, this technology was not adopted on any major scale until the 1990s.

This thesis addresses the puzzle of why, if there was evidence of profitability, did the majority of farmers not adopt ZT during the 1980s. To solve this puzzle, the distributional consequences of ZT technology are analyzed across the different input suppliers and across different farmers.

To analyze the distributional impacts across the input suppliers, an equilibrium displacement model was built to examine the welfare implications of the switch from traditional tillage (TT) to ZT on agricultural input suppliers in the spring wheat industry in 1989. The model treats the technological change by either incorporating it into the production function using the factor-augmenting technical change approach to reflect the change in the efficiency of the production factors, or by shifting the input supply curves to reflect the change in the price of production factors. Because of its equilibrium structure, the model allows for changes in the efficiency and price of the affected factors to influence all production factors.

The switch from TT to ZT requires a change in the methods of weed control and in seeding operations, which in turn affect machinery service, labour, fuel and herbicide input requirements. A representative farm of an average size and soil moisture, growing spring wheat in 1989, is used to estimate the changes in the requirements of the affected inputs under TT and ZT systems. These estimations indicate that the switch from TT to ZT decreases the quantity needed of farm–owned labour by 31% and of fuel by 39%, increases the quantity needed of herbicide by 48%, increases the cost per unit of herbicide by 6.6%, and decreases the cost of machinery service by 11%.

Shocking the market equilibrium by these values, the changes in input prices and quantities are estimated and, consequently, the changes in the economic welfare to the input suppliers are calculated. The results of the base run analysis reveal that the move to ZT decreases the rent accruing to fuel owners, increases the rent received by the owners of land, machinery, herbicide and other variable inputs (e.g., seed, fertilizer), and has no effect on rent to farm–owned labour. The aggregate change in the return to the industry is positive, with most of the increase accruing to land owners. The increase in the return to the land sector is due to the increase in the demand of this input when moving to ZT technology, and the low supply elasticity of land.

The return to land sector is sensitive to the effectiveness of the machinery used under ZT, as well as to the change in the price of herbicide and of output (spring wheat). We found that a 10% increase in the percentage change of machinery service cost results in 9% decrease in the return to land sector; a 10% increase in the percentage change of the herbicide cost results in a 1.8% decrease in the return to land sector; and a 10% increase in the price of output results in a 10% increase in the return to land sector.

To examine the distributional impacts across farmers, the effects of neighbourhood and farmer characteristics on the adoption of ZT are examined. To meet this objective, a theoretical model of heterogeneous farmers' decision-making is developed under a waiting option framework. The theoretical predictions are then empirically tested using a panel dataset from 1991 to 2006 constructed at the census consolidated subdivision (CCS) level for the three Prairie provinces.

The theoretical model assumes that since ZT is notable for its complexity and irreversibility, there is a value in waiting to make the investment in this technology. Waiting enables potential adopters to acquire more information on the performance of ZT from neighbours who have already used the technology. Waiting thus increases the stock of knowledge and positively influences the adoption of ZT. In addition, the model assumes that farmers differ in the relative returns they receive from growing a crop under ZT and TT technology. The source of differences resides in farmers socio-economic conditions and management skills, and in environmental and geographical conditions under which they operate.

The theoretical predictions of the model are empirically tested using a random-effects (RM) generalized least squares (GLS) framework. Farmer heterogeneity is captured by two sets of variables: farmer personal characteristics and farm business characteristics. One of the important personal characteristics is a farmer's location relative to other farmers that have previously adopted the technology. This neighbourhood effect is captured by including variables that capture the fraction of farmers that have adopted ZT technology in neighbouring CCSs in the previous time period. In addition, provincial and time dummy variables are introduced in the analysis to control for the unobserved features that are not explicitly captured by the model.

To correct for spatial correlation, the empirical model is estimated using the clustering approach. The multicollinearity and omitted variable problems are addressed by examining four alternative specifications. All models specifications strongly support the positive effect of the neighbourhood effect on the adoption of ZT technology, indicating that the results are robust to various specification changes.

The results of the final model show that the 100 km neighbourhood effect, education, farm ownership, farm size, and high soil erosion risk class significantly and positively influence the adoption of ZT technology. Distance to research station and brown soil type significantly and negatively impact the ZT adoption. Age, off-farm employment, and the 100-200 km and 200-300 km neighbourhood effect variables are found to be insignificant. Provincial dummies show that, compared to Manitoba, the adoption of ZT is higher in Saskatchewan and Alberta. Time dummy variables indicate that, compared to 1996, the adoption of ZT increased in both 2001 and 2006.

6.1 Findings and Recommendations for Future Research

The results of this thesis provide insights into the puzzle that was posed at the beginning of the thesis, namely, "Why, if there was evidence of profitability, did the majority of farmers not adopt ZT technology during the 1980s?". We found evidence that for some farmers the adoption of ZT technology was profitable in the late 1980s. Two critical factors of ZT profitability were land ownership and the effectiveness of ZT equipment technology. Since land operators do not capture any rent from the adoption of ZT technology, and since they have to pay more for herbicides (i.e., glyphosate) and equipment, they would not have had the incentive to adopt ZT in the late 1980s. It is also likely that in the late 1980s only a small group of farmers would have found the existing zero tillage equipment (e.g., no-till drills) to be really effective. Since the profitability of ZT is sensitive to equipment effectiveness, it is likely that many farmers operating in 1989 would not have found ZT to be profitable, even if they did own land. On this basis, the adoption of ZT in the 1990s can be seen to be in part the result of improvements in the seeding equipment and technology (e.g., the development of the air-seeder).

The results of the regression analysis indicate that the neighbourhood effect is an important factor in the adopt ZT. This means that if we get a small group of farmers to adopt the technology then, through social interactions with other farmers, they will positively influence the adoption of this technology in their neighbourhood over time. Indeed, the percentage of cropland area under ZT in Alberta (AB), Saskatchewan (SK) and Manitoba (MB) increased from 3%, 10% and 5% in 1991 to 48%, 60% and 21% in 2006, respectively. The regression results also indicated that land ownership, large farm size, risk of soil erosion, soil type, education, and the released information from extension agents variables affect the adoption of ZT technology on the Prairies. The positive and statistically significant impact of land ownership is consistent with the findings of the equilibrium displacement model that show that land owners obtain the greatest share of the benefits from ZT adoption.

In additional to its impact on learning process, neighbourhood effect can explain the impact of a number of factors (e.g., the change in the social resistance to the zero tillage concept, similar cultural or ethnic backgrounds, and similar agronomic conditions) on the adoption of ZT.

Socially, the performance of a farming practice is determined by the feedbacks from the community, which mostly includes family members and neighbours. The early adopters of ZT reported facing social challenges that arose because they were not following the traditional tillage culture of the farming community. The neighbourhood effect, therefore, can explain the following relationship: as the number of farmers who have adopted ZT increases, social pressures or community expectations to follow traditional tillage culture decreases, and, thus, the adoption of ZT increases in the same neighbourhood over time.

These results suggest that the distributional consequences of the ZT technological change must be assessed and taken into account when evaluating the impacts of adopting agricultural innovations since these determine the size and magnitude of the returns to different actors. Because of the positive return that they obtain, there is an incentive for land owners and the suppliers of herbicides, machinery, and other variable inputs (e.g., fertilizer and seed) to be involved in the development and adoption of ZT technology. And, once this technology began to be adopted, albeit differentially across farmers because of their differing characteristics, there is evidence that this adoption in turn leads to adoption by neighbours in subsequent periods.

Knowing the distribution of returns to technical change among agricultural input suppliers and determining the factors that affect farmers' decision to adopt a new technology are important elements to policy-makers and other groups (e.g., chemical and machinery companies) involved in funding R&D investment decisions.

An area where public policy can play a role in the development and adoption of innovations is through the establishment of agricultural associations that facilitate the flow of information among interest groups. The development and adoption of conservation tillage on the Prairies is an example where agricultural associations played an important role in facilitating the two-way flows of information among scientists, machinery engineers, and farmers. The establishment of such associations would enhance the emergence of new innovations and facilitate their adoption.

Future research might examine the influence of conservation tillage organizations on farmer's decision to adopt ZT on the Prairies. Organizations such as Alberta Conservation Tillage Society, Manitoba–North Dakota, Zero Tillage Farmers Association, and Saskatchewan Soil Conservation Association (SSCA) were established on the Prairies to deal with the social and technical complexity problems associated with the adoption of ZT. A qualitative analysis can be conducted to measure this impact using data on farmer's membership in these organizations.

As noted in the Introduction, agricultural innovation for sustainable development is necessary to satisfy human needs for a growing population. The slow and lack of adoption of sustainable practices, especially in developing countries, call for additional research to better understand the local constraints to innovation adoption and to modify practices to better suit local conditions. This study suggested that in the case of zero tillage adoption, superior economic conditions, and social and information networks allowed this technology to spread on the Canadian Prairies.

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Appendix A *Writing the Model in Matrix Form*

Equations (15) to (28) can be written in matrix form as: $MZ = G = a_1E(A_1) + a_2E(A_2) + a_3E(A_3) + a_4E(A_4) + a_5E(A_5) + a_6E(A_6) + b_1E(B_1) + b_2E(B_2) + b_3E(B_3) + b_4E(B_4) + b_5E(B_5) + b_6E(B_6)$. That is:

$$\begin{bmatrix} 1 & \eta & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & -K_1 & -K_2 & -K_3 & -K_4 & -K_5 & -K_6 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & V_1 & -\frac{K_2}{\sigma_{12}} & -\frac{K_3}{\sigma_{13}} & -\frac{K_4}{\sigma_{14}} & -\frac{K_5}{\sigma_{15}} & -\frac{K_6}{\sigma_{16}} & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & -\frac{K_1}{\sigma_{12}} & V_2 & -\frac{K_3}{\sigma_{23}} & -\frac{K_4}{\sigma_{24}} & -\frac{K_5}{\sigma_{25}} & -\frac{K_6}{\sigma_{26}} & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & -\frac{K_1}{\sigma_{13}} & -\frac{K_2}{\sigma_{23}} & V_3 & -\frac{K_4}{\sigma_{34}} & -\frac{K_5}{\sigma_{35}} & -\frac{K_6}{\sigma_{36}} & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & -1 & -\frac{K_1}{\sigma_{14}} & -\frac{K_2}{\sigma_{24}} & -\frac{K_3}{\sigma_{34}} & V_4 & -\frac{K_5}{\sigma_{45}} & -\frac{K_6}{\sigma_{46}} & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & -\frac{K_1}{\sigma_{15}} & -\frac{K_2}{\sigma_{25}} & -\frac{K_3}{\sigma_{35}} & -\frac{K_4}{\sigma_{45}} & V_5 & -\frac{K_6}{\sigma_{56}} & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & -\frac{K_1}{\sigma_{16}} & -\frac{K_2}{\sigma_{26}} & -\frac{K_3}{\sigma_{36}} & -\frac{K_4}{\sigma_{46}} & -\frac{K_5}{\sigma_{56}} & V_6 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & -1/e_1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1/e_2 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1/e_3 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -1/e_4 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1/e_5 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1/e_6 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} E(Y) \\ E(P) \\ E(X_1) \\ E(X_2) \\ E(X_3) \\ E(X_4) \\ E(X_5) \\ E(X_6) \\ E(P_1) \\ E(P_2) \\ E(P_3) \\ E(P_4) \\ E(P_5) \\ E(P_6) \end{bmatrix} =$$

$$
\begin{bmatrix} 0 \\ K_1 \\ 1-V_1 \\ \frac{K_1}{\sigma_{12}} \\ \frac{K_1}{\sigma_{13}} \\ \frac{K_1}{\sigma_{14}} \\ \frac{K_1}{\sigma_{15}} \\ \frac{K_1}{\sigma_{16}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_1) +
\begin{bmatrix} 0 \\ K_2 \\ \frac{K_2}{\sigma_{12}} \\ 1-V_2 \\ \frac{K_2}{\sigma_{23}} \\ \frac{K_2}{\sigma_{24}} \\ \frac{K_2}{\sigma_{25}} \\ \frac{K_2}{\sigma_{26}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_2) +
\begin{bmatrix} 0 \\ K_3 \\ \frac{K_3}{\sigma_{13}} \\ \frac{K_3}{\sigma_{23}} \\ 1-V_3 \\ \frac{K_3}{\sigma_{34}} \\ \frac{K_3}{\sigma_{35}} \\ \frac{K_3}{\sigma_{36}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_3) +
\begin{bmatrix} 0 \\ K_4 \\ \frac{K_4}{\sigma_{14}} \\ \frac{K_4}{\sigma_{24}} \\ \frac{K_4}{\sigma_{34}} \\ 1-V_4 \\ \frac{K_4}{\sigma_{45}} \\ \frac{K_4}{\sigma_{46}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_4) +
\begin{bmatrix} 0 \\ K_5 \\ \frac{K_5}{\sigma_{15}} \\ \frac{K_5}{\sigma_{25}} \\ \frac{K_5}{\sigma_{35}} \\ \frac{K_5}{\sigma_{45}} \\ 1-V_5 \\ \frac{K_5}{\sigma_{56}} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_5) +
$$

$$
\begin{bmatrix} 0 \\ K_6 \\ \frac{K_6}{\sigma_{16}} \\ \frac{K_6}{\sigma_{26}} \\ \frac{K_6}{\sigma_{36}} \\ \frac{K_6}{\sigma_{46}} \\ \frac{K_5}{\sigma_{56}} \\ 1-V_6 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(A_6) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(B_1) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(B_2) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} E(B_3) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} E(B_4) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} E(B_5) +
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} E(B_6)
$$

where

$$
V_1 = \Big(\frac{K_2}{\sigma_{12}} + \frac{K_3}{\sigma_{13}} + \frac{K_4}{\sigma_{14}} + \frac{K_5}{\sigma_{15}} + \frac{K_6}{\sigma_{16}}\Big),\ V_2 = \Big(\frac{K_1}{\sigma_{12}} + \frac{K_3}{\sigma_{23}} + \frac{K_4}{\sigma_{24}} + \frac{K_5}{\sigma_{25}} + \frac{K_6}{\sigma_{26}}\Big),
$$

$$
V_3 = \Big(\frac{K_1}{\sigma_{13}} + \frac{K_2}{\sigma_{23}} + \frac{K_4}{\sigma_{34}} + \frac{K_5}{\sigma_{35}} + \frac{K_6}{\sigma_{36}}\Big),\ V_4 = \Big(\frac{K_1}{\sigma_{14}} + \frac{K_2}{\sigma_{24}} + \frac{K_3}{\sigma_{34}} + \frac{K_5}{\sigma_{45}} + \frac{K_6}{\sigma_{46}}\Big),
$$

$$
V_5 = \Big(\frac{K_1}{\sigma_{15}} + \frac{K_2}{\sigma_{25}} + \frac{K_3}{\sigma_{35}} + \frac{K_4}{\sigma_{45}} + \frac{K_6}{\sigma_{56}}\Big),\ \text{and}\ V_6 = \Big(\frac{K_1}{\sigma_{16}} + \frac{K_2}{\sigma_{26}} + \frac{K_3}{\sigma_{36}} + \frac{K_4}{\sigma_{46}} + \frac{K_5}{\sigma_{56}}\Big)
$$

Appendix B

Machinery Work Rate and Hours of Use for an Average Farm in 1989

Machinery	Work Rate	Hours of Use	
		TT	ZT
Tractors	–	820	400
Cultivator H.D.[a]	18.50 AC/hr	390	–
Harrows	30.00 AC/hr	60	–
Rock Picker	30.00 AC/hr	60	–
Drill Disc Press	12.00 AC/hr	150	–
Drill No-till Disc	12.00 AC/hr	–	150
Granular Herb. Appl.	20.00 AC/hr	90	–
Sprayer PT 500 gal[b]	27.00 AC/hr	200	–
Sprayer PT 800 gal[c]	35.00 AC/hr	–	250
Grain Auger out[d]	3000 bu/hr	16	16
Grain Auger in	6000 bu/hr	8	8
Combines	11.00 AC/hr	164	164
Swather SP DSA	9.50 AC/hr	190	190
Grain Dryer[d]	500 bu/hr	97	97
Pickup	–	200	200
Grain Truck	–	300	300

Sources: Saskatchewan Ministry of Agriculture–Farm Machinery 1990 and 2010

[a] Cultivator hours of use calculation is based on the assumption of four tillage passes under TT

[b] Sprayer PT 500 gal hours of use calculation is based on the assumption of 3 spraying passes under TT

[c] Sprayer PT 800 gal hours of use calculation is based on the assumption of 5 spraying passes under ZT

[d] Grain augers and grain dryer hours of use are calculated based on an average yield equal to 27 bu/acre

Machinery Depreciation Life and Repair Cost Factors

Machinery	Depreciation Life/YR		Repair Cost Factor/
	TT	ZT	hr/$1000
Tractor Primary	11.00	14.50	0.052
Cultivator H.D.	12.00	–	0.220
Harrows	19.60	–	0.270
Rock Picker	11.00	–	0.312
Drill Disc Press	15.00	–	0.200
Drill No–till Disc	–	15.00	0.200
Granular Herb. Appl.	15.00	–	0.375
Sprayer PT 500 gal	5.00	–	0.200
Sprayer PT 800 gal	–	5.00	0.200
Grain Augers out	18.00	18.00	0.400
Grain Augers in	20.00	20.00	0.400
Combines	12.00	12.00	0.213
Swather SP DSA	11.00	11.00	0.290
Grain Dryer	18.00	18.00	0.120
Pickup	10.50	10.50	0.124
Grain Truck	10.00	10.00	0.166

Sources: Saskatchewan Ministry of Agriculture-Farm Machinery 1990.

Machinery Fuel Requirement and Price, and Fuel Consumption (Liter/HR)

Machinery	Fuel Type	Fuel Price	Liter/HR
Tractor Primary	Diesel		64.00
Tractor Secondary	Diesel	0.42	28.00
Combines	Diesel		32.00
Swather SP DSA	Diesel		14.00
Pickup	Gasoline		14.00
Grain Truck	Gasoline	0.48	23.00
Grain Augers out	Gasoline		1.00
Grain Dryer Continuous	Propane	0.35	80.00

Source: Saskatchewan Ministry of Agriculture–Farm Machinery 1990